Contemporary Physics Education Project

Introduction to Plasma and Fusion Science

October 22, 2019

APS Division of Plasma Physics Meeting

Teacher's Day

Workshop Leaders

Contemporary Physics Education Project

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Westminster College, New Wilmington, PA (emeritus)

Assisted by:

Cherie Harper (gsphysics@live.com)
Greensburg Salem High School, Greensburg, PA

All are associated with CPEP
(Contemporary Physics Education Project)

Contemporary Physics Education Project

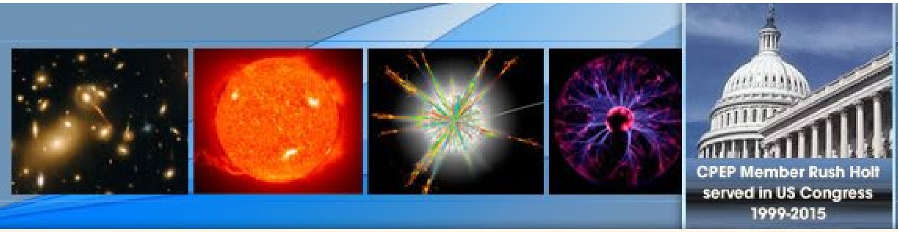
- CPEP is a non-profit organization of teachers, educators, and physicists located around the world.
- Purpose: "…to develop, test, and produce curriculum materials for the purpose of improving instruction in introductory physics course."

  CPEP charts, brochures, web features, and classroom activities present the current understanding of the fundamental nature of matter and energy, incorporating the major research findings of recent years.
- During the last twenty years, CPEP has distributed nearly half a million copies of its charts and other products.

www.CPEPphysics.org

www.CPEPphysics.org

CPEP
Contemporary Physics Education Project



CPEP awarded 2017

EXCELLENCE IN PHYSICS EDUCATION AWARD

by the American Physical Society

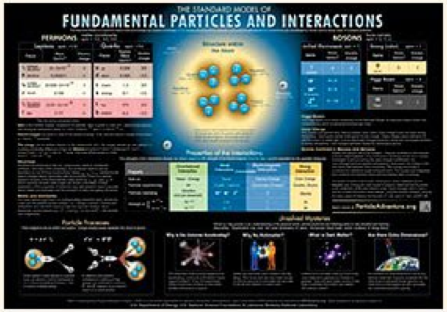
"For leadership in providing educational materials on contemporary physics topics to students for over 25 years."

The Contemporary Physics Education Project is a non-profit organization of teachers, educators, and physicists located around the world. CPEP materials present the current understanding of the fundamental nature of matter and energy, incorporating the major research findings of recent years. During the last twenty years, CPEP has distributed almost half a million copies of its charts and other products.

PRODUCT LIST
Now available on Amazon!

Learn about and apply now for the:
CPEP Award for Excellence in Teaching Contemporary Physics

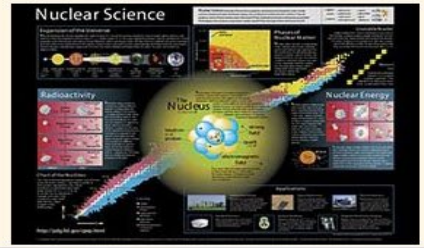
FUNDAMENTAL PARTICLES AND INTERACTIONS



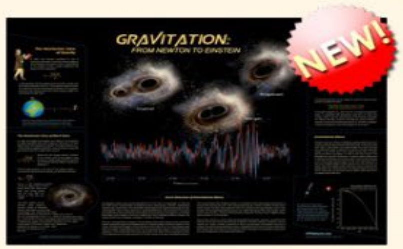
PLASMA PHYSICS AND FUSION

THE HISTORY AND FATE OF THE UNIVERSE

NUCLEAR SCIENCE



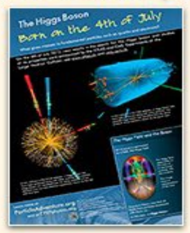
GRAVITATION



2017 Nobel Prize in Physics for 3 members of the LIGO/Virgo team for the discovery of gravitational waves.

Learn more about the discovery from CPEP's latest poster!

The Higgs Boson
"Born on the 4th of July" Poster



HONORS FOR CPEP LEADERS | JOIN CPEP MAILING LIST | FUNDING CREDITS

CONTACT

CPEP Posters have appeared in the following movies and TV shows:

DONNIE DARKO HULK Thirteen Conversations About One Thing BIG BANG theory

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Contemporary Physics Education Project

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Address http://www.cpepweb.org/nobel.html Go

Contemporary Physics Education Project

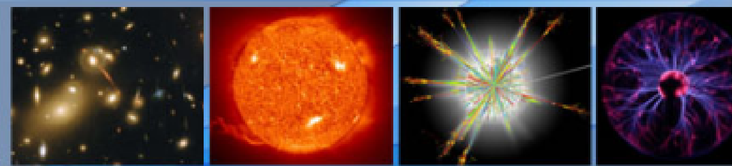
20th Anniversary

Home | Fundamental Particles | Plasma Physics and Fusion | History and Fate of the Universe | Nuclear Science

George Smoot with the Nobel Prize and in the background the CPEP chart, the History and Fate of the Universe, whose production he led.	Click to see the Nobel Prize Foundation's description of the Mather/Smoot prize.

start | Novell GroupWise... | Orlando-2007 | PlasmaIntro-DPP... | PlasmaIntro-DPP... | CPEP - Contempo... | CPEP - Contempo... | 2:56 PM

CPEP
Contemporary Physics Education Project



Cheryl Harper wins a Kavli Prize

CPEP member Cheryl Harper won a prize in a contest for the best secondary school science class presentations on the subject of Particle Physics in the Age of the Large Hadron Collider. These presentations were based on the 2008 KITP Teacher's Conference at the Kavli Institute for Theoretical Physics at UC Santa Barbara. Her presentation, movie, and homework are online at:

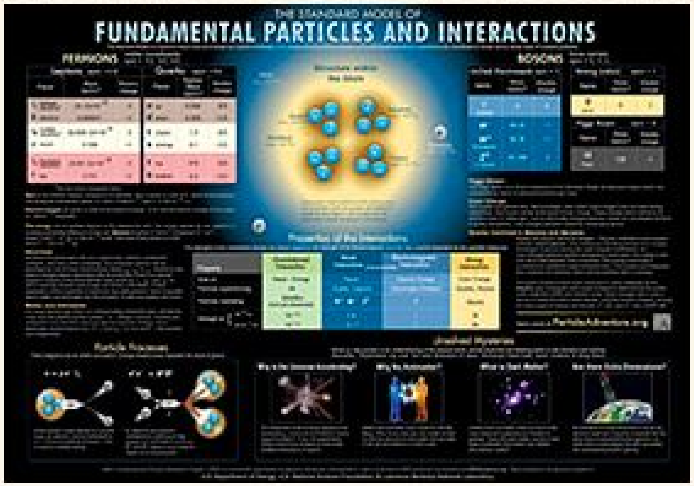
2008 RAAB CONTEST WINNERS

The Contemporary Physics Education Project is a non-profit organization of teachers, educators, and physicists located around the world. CPEP materials present the current understanding of the fundamental nature of matter and energy, incorporating the major research findings of recent years. During the last twenty years, CPEP has distributed almost half a million copies of its charts and other products.

PRODUCT LIST

Now available on Amazon!

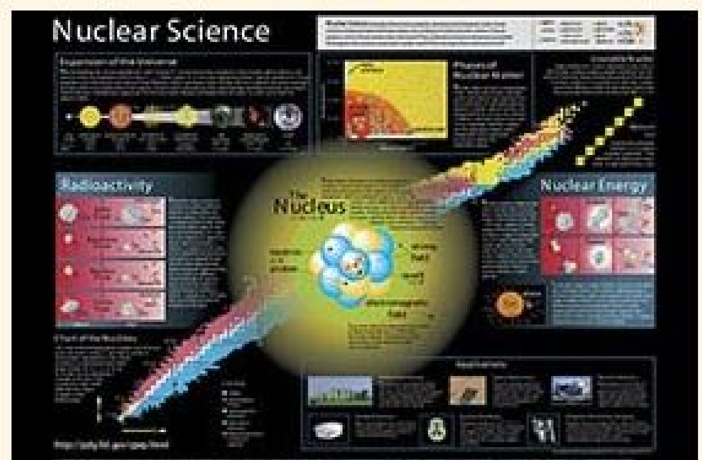
FUNDAMENTAL PARTICLES AND INTERACTIONS



PLASMA PHYSICS AND FUSION

THE HISTORY AND FATE OF THE UNIVERSE

NUCLEAR SCIENCE



CPEP - Contemporary Physics Education Project - CPEP - Mozilla Firefox

File Edit View History Bookmarks Tools Help

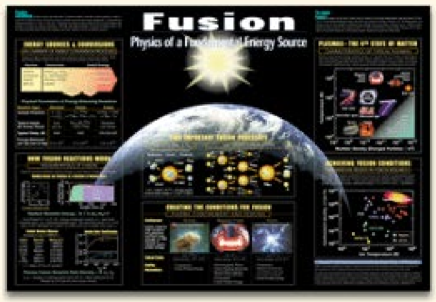
http://www.cpepweb.org/fusion.html

Google

CPEP materials about...

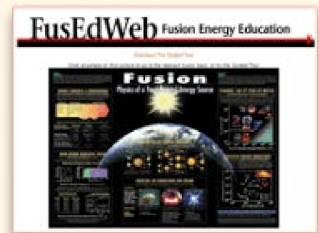
Plasma Physics and Fusion

Fusion Chart

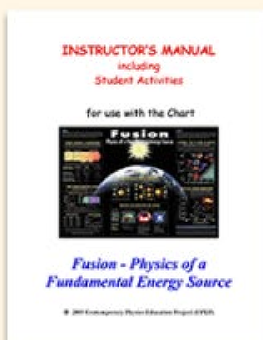


Info and Ordering

CPEP: Online Fusion Course



Instructor's Manual



Sample Pages

Student Activities

Done

CPEP materials about...

Plasma Physics and Fusion

Student Activities

These activities can be used to supplement the topics on the Teaching Chart, ***Fusion: Physics of a Fundamental Energy Source***, produced by the Contemporary Physics Education Project (CPEP). Teachers may reproduce these activities for their classroom use as long as they include credit to CPEP. Separate Teacher's Notes include equipment information, background information and suggestions, expected results, and answers to the questions that are asked in the student activity.

The following activities are intended for use in high school and introductory college courses. An appendix to the Teacher's Notes shows the alignment of the activity with the National Science Standards and with the AAAS Benchmarks. Video demonstrations of three of the activities are available below. Click here for a brief summary of the activities.

Simulating Fusion - Download English Version PDF | Word
Download French Version PDF | Word
Download Spanish Version PDF | Word
Long Range Repulsion, Short Range Attraction - Download: PDF | Word
Motion of Charged Particles in a Magnetic Field - Download: PDF | Word | Video
The Physics of Plasma Globes - Download: PDF | Word | Video
Plasma Globes and "Body Capacitance" - Download: PDF | Word
Studying the Electric Field Near a Plasma Globe - Download: PDF | Word
Properties of a Plasma: Half-Coated Fluorescent Bulbs - Download: PDF | Word | Video
Resistance of a Fluorescent Bulb: Half-coated Bulb Version - Download: PDF | Word
Resistance of a Fluorescent Bulb: Plasma Tube with Power Supply Version - Download: PDF | Word

The following activities are intended for use in middle school classes.

Testing a Physical Model - Download: PDF | Word
Modeling the Interactions in a Nucleus - Download: PDF | Word
Plasma Globe and Spectra - Download: PDF | Word

Teacher's Notes available here for each of the above activities.

CPEP - Contemporary Physics Education Project - CPEP - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.cpepweb.org/fusion_teacher_access.html

CPEP Contemporary Physics Education Project

CPEP materials about...

Plasma Physics and Fusion

Educator Access to Teacher's Notes - Password Required

Password: [ ] Enter

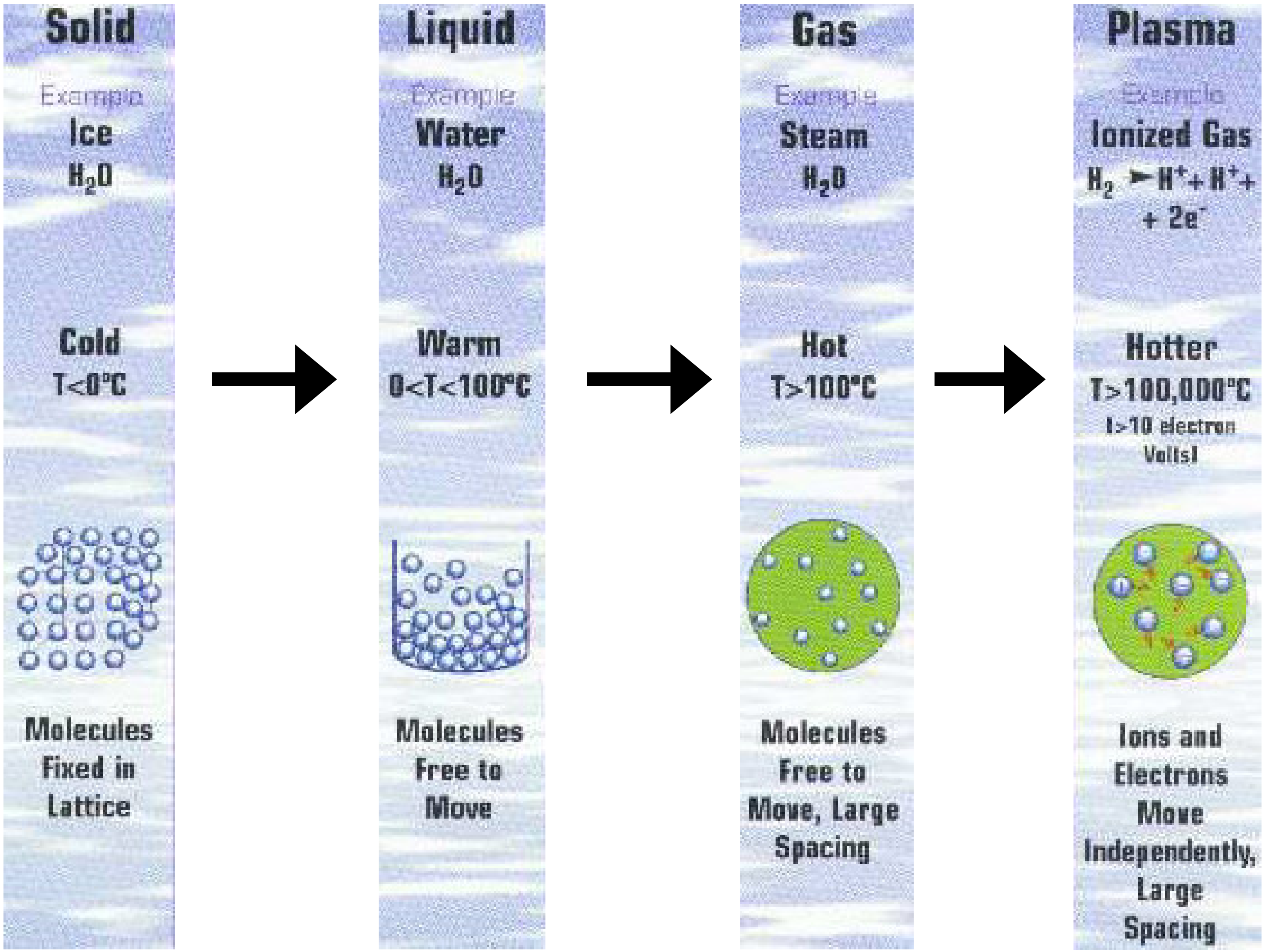
If you are an educator and want this password, send an email to **fusion @ cpepweb.org** with the following information:

- your name and title or position
- your school or institution
- fact that you want a password
- your email to send password confirmation
- contact email for your supervisor (department chair, principal, etc.) in case we need verification.

Done

What is a Plasma?

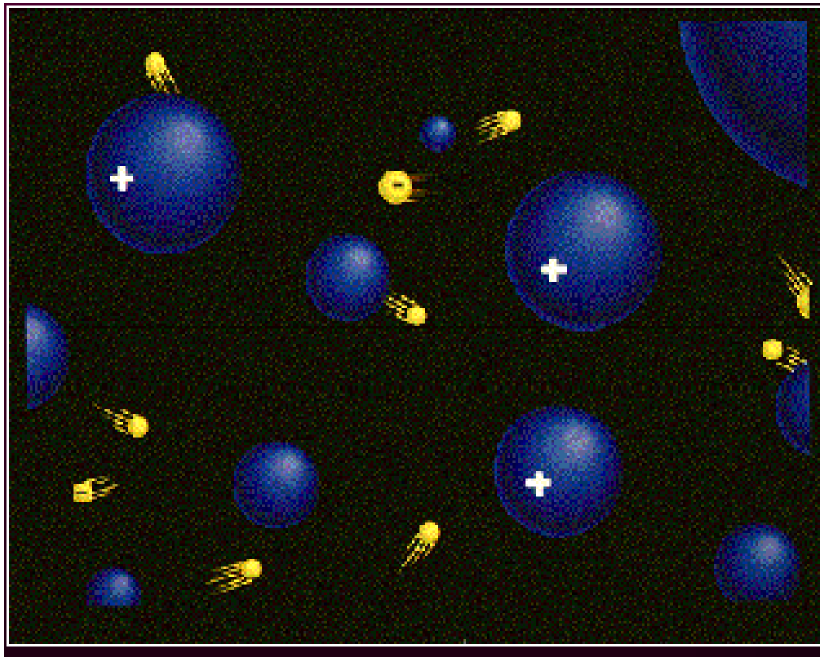
Contemporary Physics Education Project



What is a Plasma?

Contemporary Physics Education Project

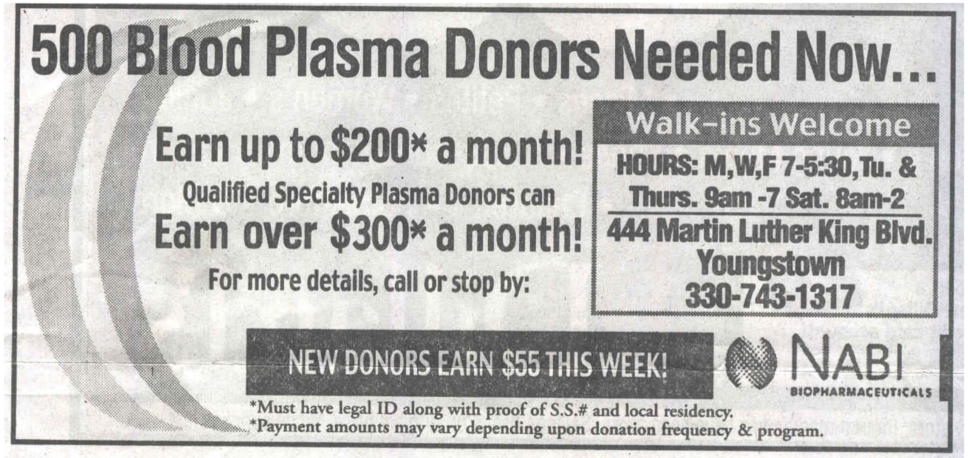
- Fourth State of Matter (Should it be the 1st State?)
- A plasma is an ionized gas.
- A collection of positively and negatively charged particles.
- Plasmas interact strongly with electric and magnetic fields.



What is a Plasma?

‘Plasma’ was coined by Tonks and Langmuir in (1929):
“...when the electrons oscillate, the positive ions behave like a rigid jelly...”

Also: The fluid part of blood, lymph, or milk.
But this is **NOT** what we are considering!


500 Blood Plasma Donors Needed Now...
Earn up to $200* a month!
Qualified Specialty Plasma Donors can
Earn over $300* a month!
For more details, call or stop by:
Walk-ins Welcome
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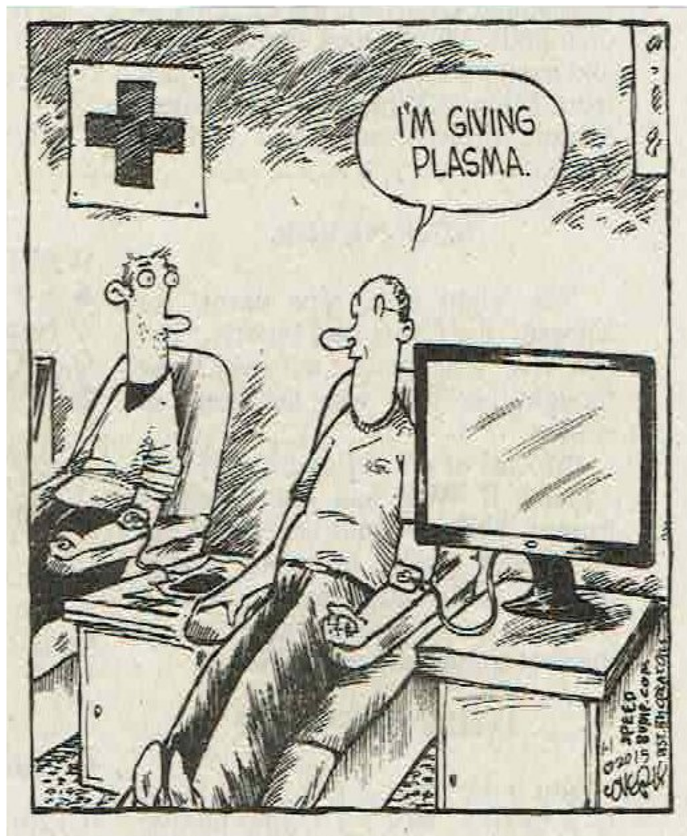
I'M GIVING PLASMA.

Quiz

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What percent of the human body is plasma?

Zero

What percent of the earth is plasma?

Almost zero

What percent of the solar system is plasma?

More than 99%

What percent of the observable universe is plasma?

Almost 100%

Where do we find plasmas?

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- Examples of plasmas on Earth
  - Lightning
  - Neon and Fluorescent Lights
  - Laboratory Experiments
  - Plasma Globes (Balls)
  - Plasma displays
  - Manufacturing
  - Aurora
- Examples of astrophysical plasmas:
  - The sun and the solar wind
  - Stars, interstellar medium

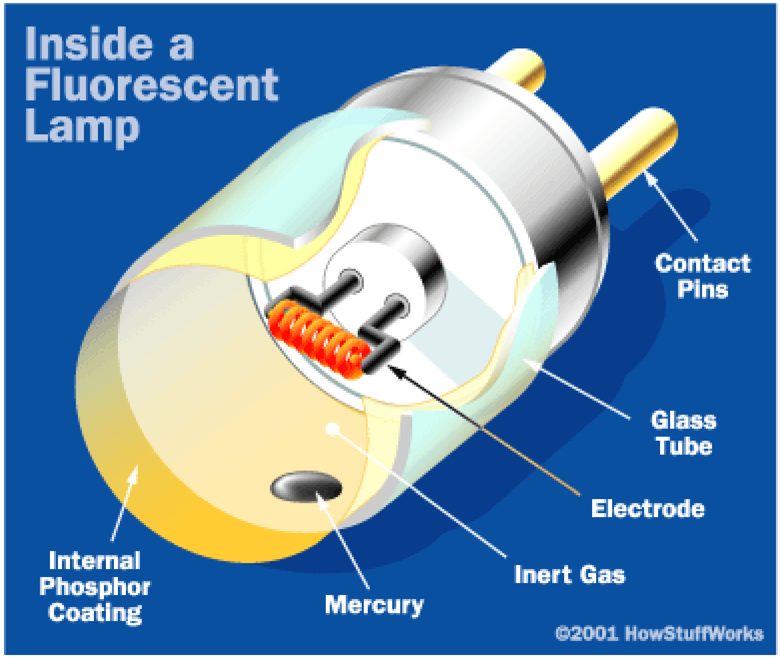
Plasmas on Earth

Contemporary Physics Education Project

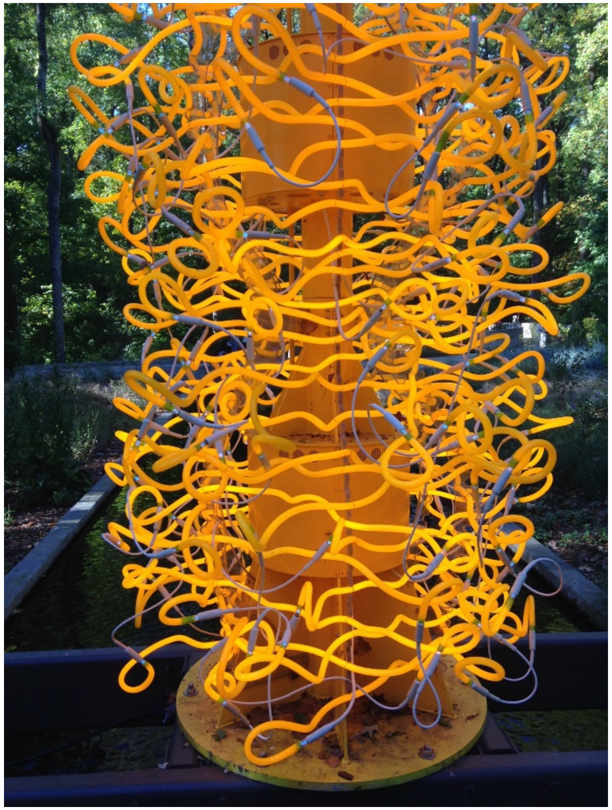
Plasma Globe (Ball)

Lightning

Plasmas on Earth



http://www.howstuffworks.com/plasma-display.htm
http://home.howstuffworks.com/fluorescent-lamp.htm


Plasma in Art
Dale Chihuly Glass

YouTube video from Arbor Scientific
Top 10 Demos with a Plasma Globe

https://youtu.be/RCi5rOy0Xnc

Astrophysical Plasmas

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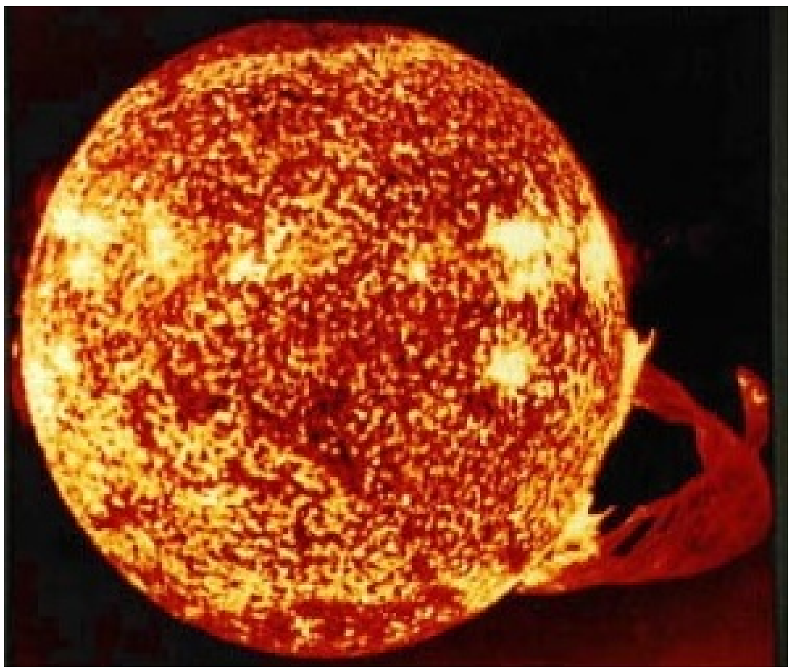
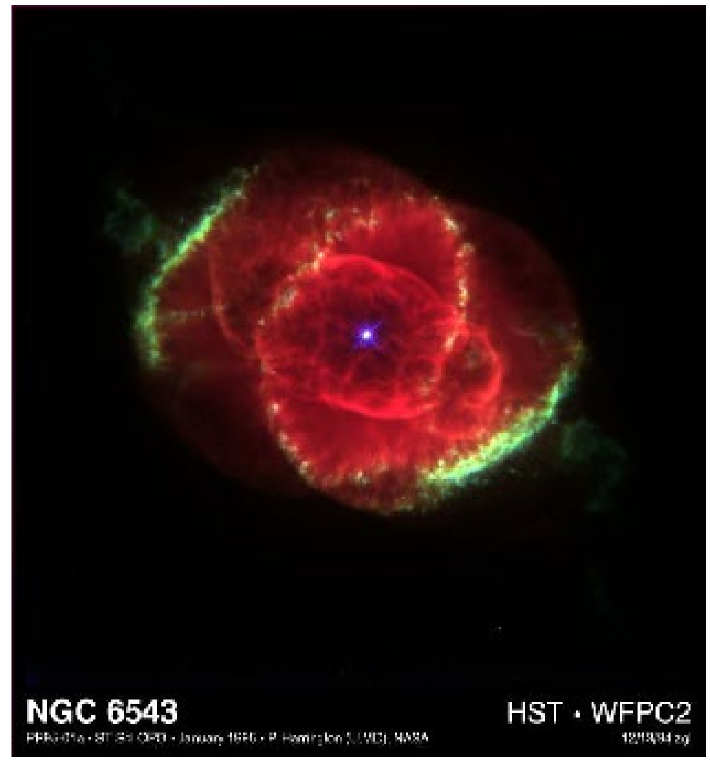
The Sun



Catseye Nebula



Solar Corona During Eclipse

Contemporary Physics Education Project

Did you view the 2017 eclipse?

http://www.mreclipse.com/SEphoto/SEgallery3/SEgallery3.html

The solar wind (a plasma) interacts with the Earth's magnetic field

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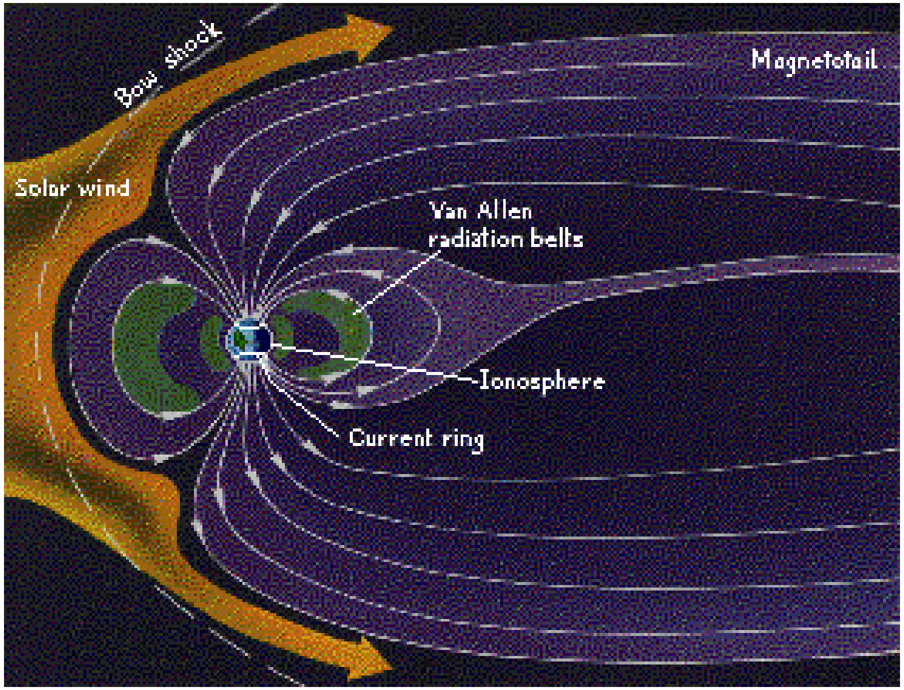
The sun emits mass in the form of plasma at velocities of up to 500 km/s.

This solar wind causes the Earth's magnetic field to compress creating a shock wave called the Bow wave.



From Stars, James Kaler

Interactions between the earth's magnetic field and a plasma can have spectacular results

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The northern lights (aurora borealis)

Photo by David Fritz
http://www.pfrr.alaska.edu/aurora/index.html

Interactions between the earth's magnetic field and a plasma can have spectacular results

Contemporary Physics Education Project

The northern lights (aurora borealis)

Photo by Jan Curtis
http://www.geo.mtu.edu/weather/aurora/images/aurora/jan.curtis/

Plasmas of all kinds

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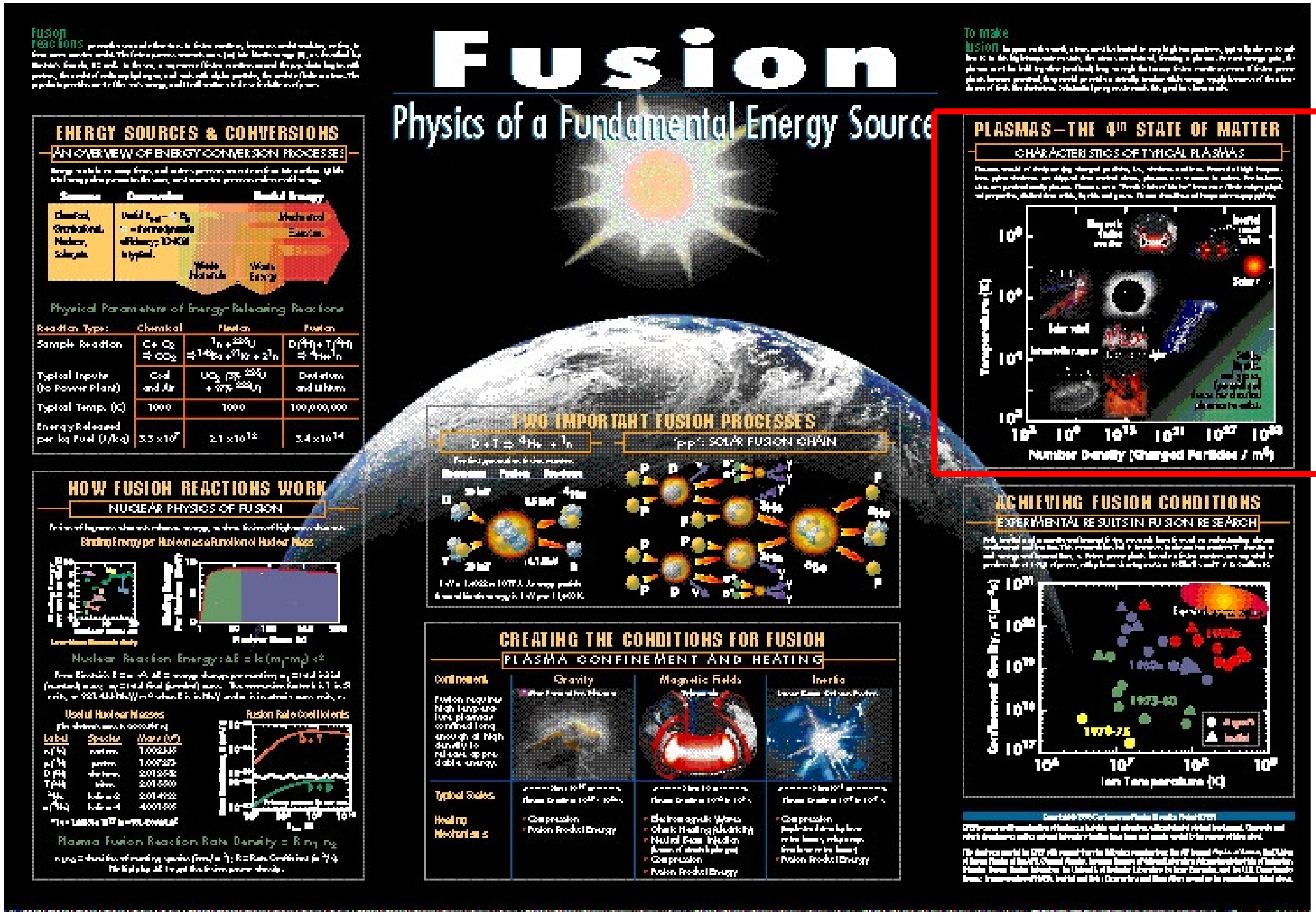
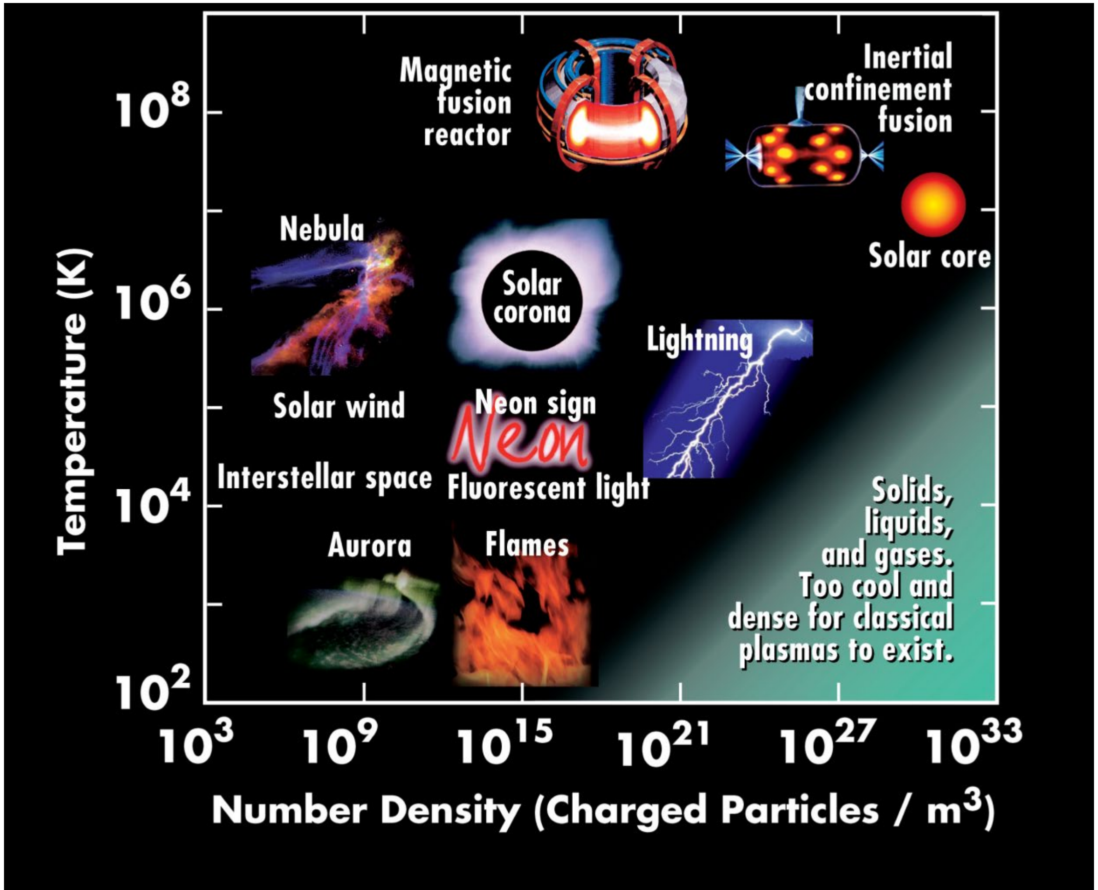
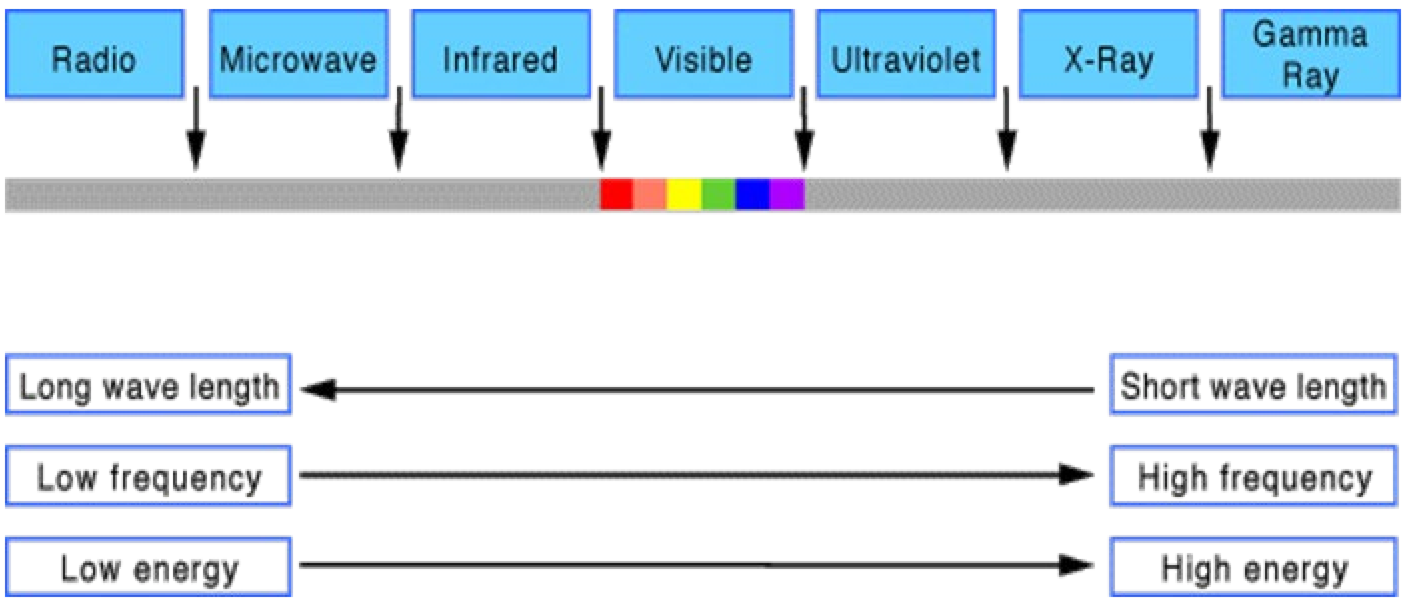


Plasmas of all kinds



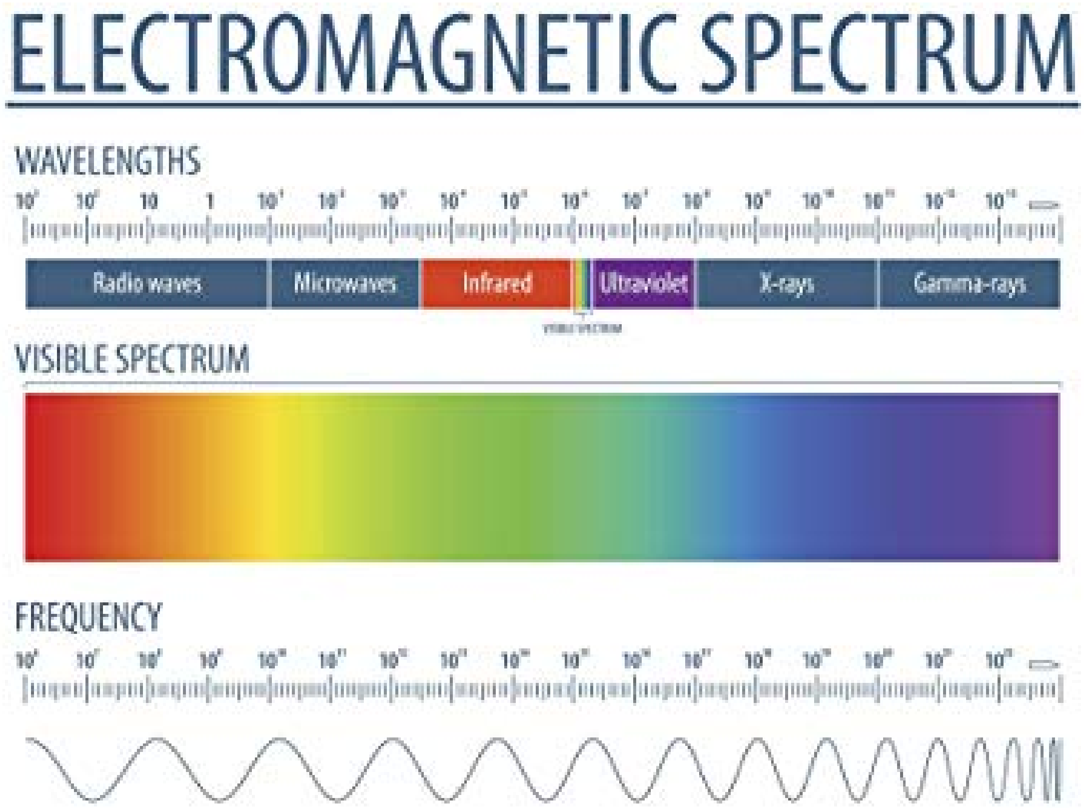
What causes the colors in the plasma?

Reminder: Electromagnetic Spectrum



R O Y G B I V

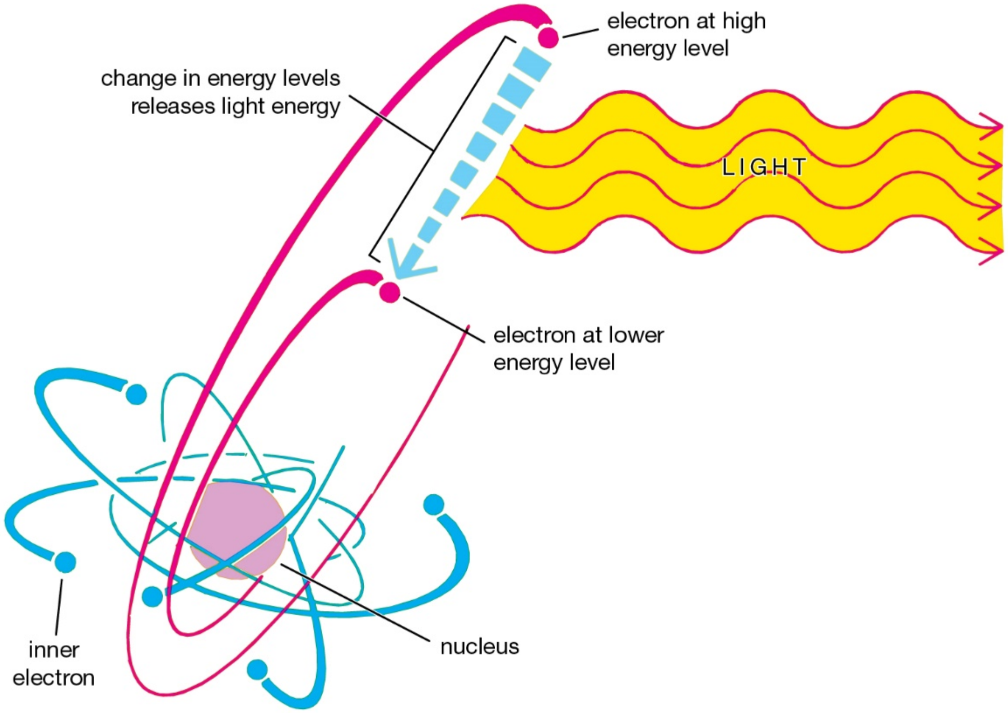
What causes the colors in the plasma?



R O Y G B I V

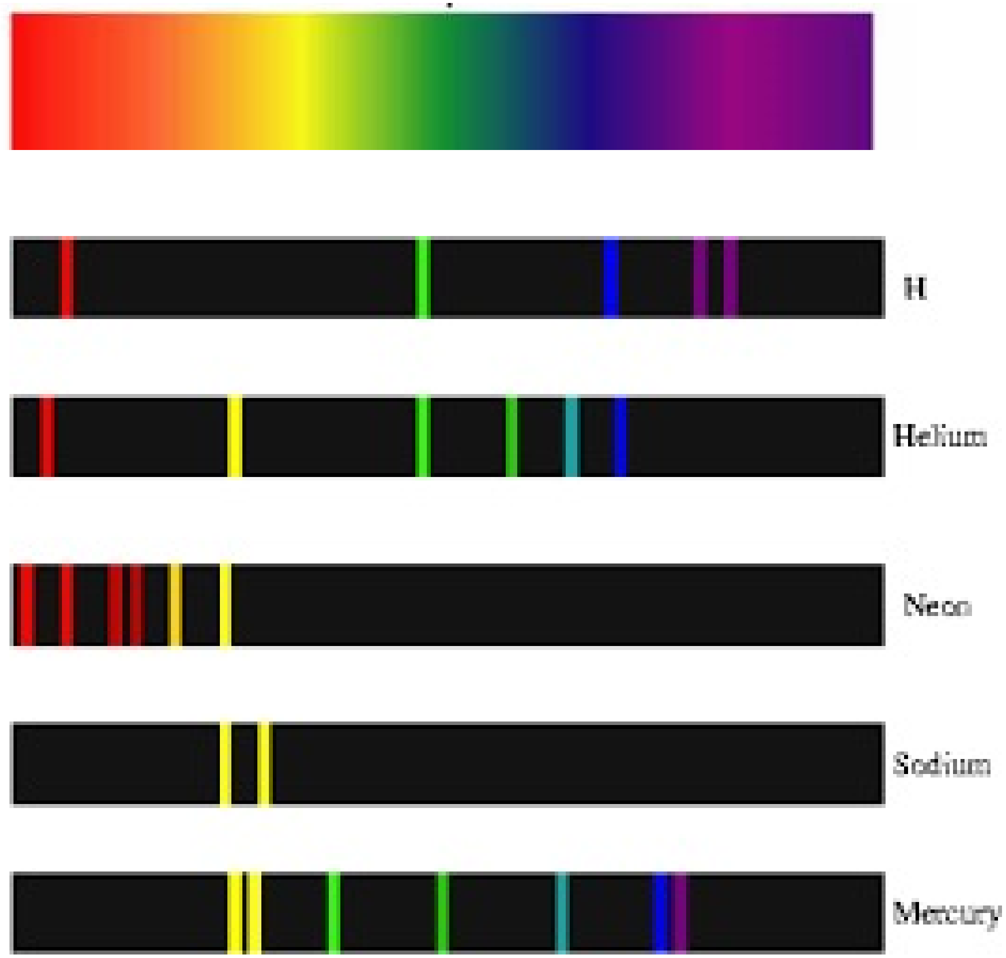
What causes the colors in the plasma?

When an electron goes from a higher energy state to a lower energy state it gives off energy as light associated with that energy.



What causes the colors in the plasma?

Energy levels in atoms are unique and so the spectra of different atoms show a unique set of wavelengths. Our eyes see these combinations as a particular color.



What causes the colors in the plasma?

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- Recall a plasma is an ionized gas, so energy has been used to remove an electron – to higher state.
- Some of these ions recapture the missing electron, it goes to a lower state, giving off energy.
- The energy given off is emitted as light of a wavelength characteristic of that atom.
- This is the light we see.

http://solar-center.stanford.edu/comics/

Why are we interested in plasmas?

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Astrophysics

Understanding plasmas helps us understand stars and stellar evolution

Upper atmospheric dynamics

The upper atmosphere is a plasma.

Plasma Applications

Plasmas can be used to build computer chips, to clean up toxic waste, for display panels.

(www.plasmacoalition.org/about-plasma.html)
(www.plasmas.org/applications.htm)

INDUSTRIAL / COMMERCIAL APPLICATIONS OF PLASMAS

Processing
◊ Surface Processing
◊ Nonequilibrium (low pressure)
◊ Thermal (high pressure)

Volume Processing
◊ Flue gas treatment
◊ Metal recovery
◊ Waste treatment

Chemical Synthesis
◊ Plasma spraying
◊ Diamond film deposition
◊ Ceramic powders

Light Sources
◊ High intensity discharge lamps
◊ Low pressure lamps
◊ Specialty sources

Surface Treatment
◊ Ion implantation
◊ Hardening
◊ Welding
◊ Cutting
◊ Drilling

Propulsion

Flat-Panel Displays
◊ Field-emitter arrays
◊ Plasma displays

Radiation Processing
◊ Water purification
◊ Plant growth

Switches
◊ Electric power
◊ Pulsed power

Energy Converters
◊ MHD converters
◊ Thermionic energy converters

Medicine
◊ Surface treatment
◊ Instrument sterilization

Isotope Separation

Beam Sources

Lasers

Material Analysis

One company's product may be another company's process. The specific applications of some classes of plasmas are too numerous to list, e.g., Lasers, Lamps...
Some applications are listed as the plasma device itself; others are listed as one level beyond that, i.e., as the applications of the plasma device.

ABOUT PLASMAS

CPS is developing a series of accessible two-page write-ups about various plasma phenomena and applications. Completed pages can be accessed below in PDF format.

Please feel free to reproduce and distribute any of these two-page write-ups for educational purposes, but each only in its entirety as a Unit (see *CPS Legal Permissions* for definition of "Unit" and further details).

- About Plasmas - *Plasma – The First State of Matter* (81K)
- About Plasmas - *Solar Plasmas* (165K)
- About Plasmas - *Plasma Propulsion* (232K)
- About Plasmas - *Computer Chips and Plasma* (178K)
- About Plasmas - *Lightning* (318K)
- About Plasmas - *Plasmas for Welding* (479K)
- About Plasmas - *Plasma Display Panels* (205K)
- About Plasmas - *Cleaning the Environment* (255K)
- About Plasmas - *Destroying Biological Hazards* (391K)
- About Plasmas - *Fusion* (753K)
- About Plasmas - *Lighting Plasmas* (233K)
- About Plasmas - *Space Plasmas* (600K)
- About Plasmas - *Plasma and Flames – The Burning Question* (110K)
- About Plasmas - *Space Weather* (204K)
- About Plasmas - *Plasma Medicine* (123K)

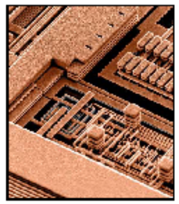
About Plasmas Example

about **Plasmas**

from the Coalition for Plasma Science

Computer Chips and Plasma

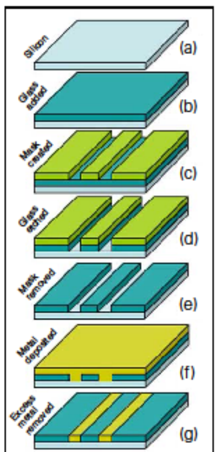
Today almost all electrical devices rely on electronic chips. Not just our computers, but our cars, our microwave ovens, our alarm clocks, even that singing birthday card – all these gadgets have chips inside. And none of these chips could be manufactured without using plasma. That's because plasma technology is capable of forming transistors and wires that are much smaller than the width of a single hair. Without plasma, the transistors would have to be made much bigger, making the chips more expensive, slower, and much less powerful.



In this microscope photo of the wiring on a chip the smallest wires are more than 100 times thinner than a single hair.

Many people are not aware of the full economic significance of using plasmas to make chips for electronics. For example, in 2005 the total global revenue generated by semiconductor chip manufacturers, like Intel Corporation and Samsung, was approximately $227 billion dollars. In the following paragraphs we will show how scientists and engineers at these companies harness the unique properties of plasma to make computer chips, and why plasma is indispensable to the continued success of the information age.

Plasma can be created by taking an ordinary gas — like air — and adding energy until electrons are stripped from the gas atoms and molecules. Usually plasma is formed by using electricity to strip electrons from these gas particles. Those electrons become very hot, typically more than 20,000°F! The hot electrons collide with gas particles, breaking many of them apart and knocking off electrons to create electrically-charged particles called ions. One of the most common plasmas is within the fluorescent light. When the light is off, that tube is filled with argon gas and mercury, but turn on the power, and the gas inside the tube is converted to glowing plasma! Plasma is also used to make computer chips. Before learning how plasma is used, it's helpful to understand how chips are made.



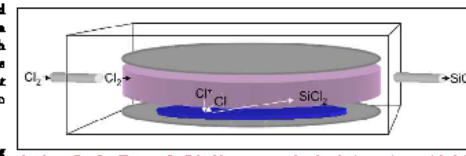
Stages of computer chip manufacture.

Chips are made like a layer cake, but with the unwanted parts of each layer removed before the next layer is applied. To create a complex, three-dimensional chip structure layer-by-layer, the two basic steps of adding a thin layer of material and then removing its unwanted parts are repeated many times. To begin, we use a flat piece of silicon (Left, Figure (a)). A thin layer of glass is added to the entire wafer as shown in (b). Next, a layer of light-sensitive film ("photoresist") is applied to the wafer. Laser light is used to remove parts of the film. The remaining film is called a "mask"(c). It protects parts of the wafer's surface from being removed during the "etch" step (d), which is the plasma process discussed below. Once the etching is complete, the mask is stripped away (e). Next, a thin film of metal is deposited on top of the wafer (f). Finally, the extra metal is polished from the wafer, leaving a layer of metal wires and glass insulation (g). More glass is added to coat the top of that layer, and the entire process is repeated over and over, creating an intricate three-dimensional network of circuit wiring. Connections between layers are made by etching small holes in the glass and filling the holes with metal.

So chips are made by depositing thin layers of glass and metal, then removing the parts of each layer that are not needed for the final chip. But how is plasma used

Continued on back

in this process? Some of the ions and fragments of molecules in the plasma are eager to react chemically with the wafer surface. These reactive components of plasma are what make it possible for engineers to create the intricate layers of a chip.



A schematic of a silicon wafer (blue) in a vacuum chamber between two metal plates (gray). The plasma is shown as purple.

As an example, let's look at etching silicon (Si) using plasma. A silicon wafer is placed in a vacuum chamber between two metal plates. The gas between the plates is removed by a vacuum pump and a small amount of chlorine gas (Cl_2) is allowed into the vacuum chamber. The metal plates are connected to a high voltage source that turns on and off about 10 million times per second. The high voltage on the plates causes the chlorine to become electrically charged, and a glowing plasma is formed directly above the wafer. The chlorine molecules are broken apart by the plasma into chlorine atoms (Cl) and ions (Cl^+). These fragments attach to the silicon atoms at the surface of the wafer and create $SiCl_2$ gas. This gas is pumped out of the plasma, removing silicon atoms in the process. A pre-patterned photoresist mask is used to protect portions of the silicon surface from Cl atoms, preventing specific regions of the wafer from being removed, as shown in steps (c)-(d) above.

A technician prepares a plasma etcher, placing the wafer on the lower metal plate. In a large commercial manufacturing environment, the wafers are handled by robots, not humans.

The process of depositing thin films on a wafer is the opposite of etching. To deposit solid material on a wafer, the input gas must contain the atoms to be deposited. For example, silane gas (SiH_4) can be used to deposit silicon using a plasma. The plasma's electrons break SiH_4 into silicon, SiH_x (x can have different values to represent different molecules), and hydrogen atoms. The silicon sticks to the surface of the wafer, and the extra hydrogen is pumped from the plasma. Within a few minutes, the silicon atoms accumulate to form a solid film of material across the entire wafer. This uniform layer of silicon then needs to be patterned with photoresist and etched to form useful devices.

Thirty years ago many of these manufacturing steps used liquid chemicals or hot gases instead of plasma. For example, simple acids were used for etching. As chips have become more sophisticated, however, the size of the transistors has become extremely small. Because acids will etch not only into the wafer but also under the mask, it is impossible to use acids to etch very small circuit patterns. Plasma, on the other hand, can etch straight into the wafer because the ions are accelerated straight from the plasma to the wafer by the high voltage used to energize the plasma. Also, since plasmas create far less hazardous waste than chemical processes, plasma-based manufacturing is much less damaging to the environment.

These are only two examples of how plasmas help create electronic chips. Plasmas are also used within the lasers needed to pattern the photoresist, and they are used to strip the photoresist from the wafer. Finally, plasmas can create "dopant" ions that modify the electrical properties of silicon, creating transistors. In fact, about half of the manufacturing steps used to make a computer chip rely on plasma. Without these vital plasma technologies, many of today's modern conveniences could not exist.

Suggested Reading:
50 Years of Science, Technology and the AVS, "Plasma Science and Technology," J. Coburn and L. Cecchi, editors, in Journal of Vacuum Science and Technology A, vol. 21(5), pp S128-S157 (2003).
Brian Chapman, Glow Discharge Processes (John Wiley & Sons, New York, 1980).

Text: Jeffrey Hopwood, Electrical and Computer Engineering Department, Tufts University. Editors: Paul Rivenberg, Gerald Rogoff
Images: Microfabrication Laboratory, Northeastern University; Microchip image courtesy of International Business Machines Corporation. Unauthorized use not permitted.

Why are we interested in plasmas?

Contemporary Physics Education Project

Astrophysics

Understanding plasmas helps us understand stars and stellar evolution

Upper atmospheric dynamics

The upper atmosphere is a plasma.

Plasma Applications

Plasmas can be used to build computer chips, to clean up toxic waste, for display panels.

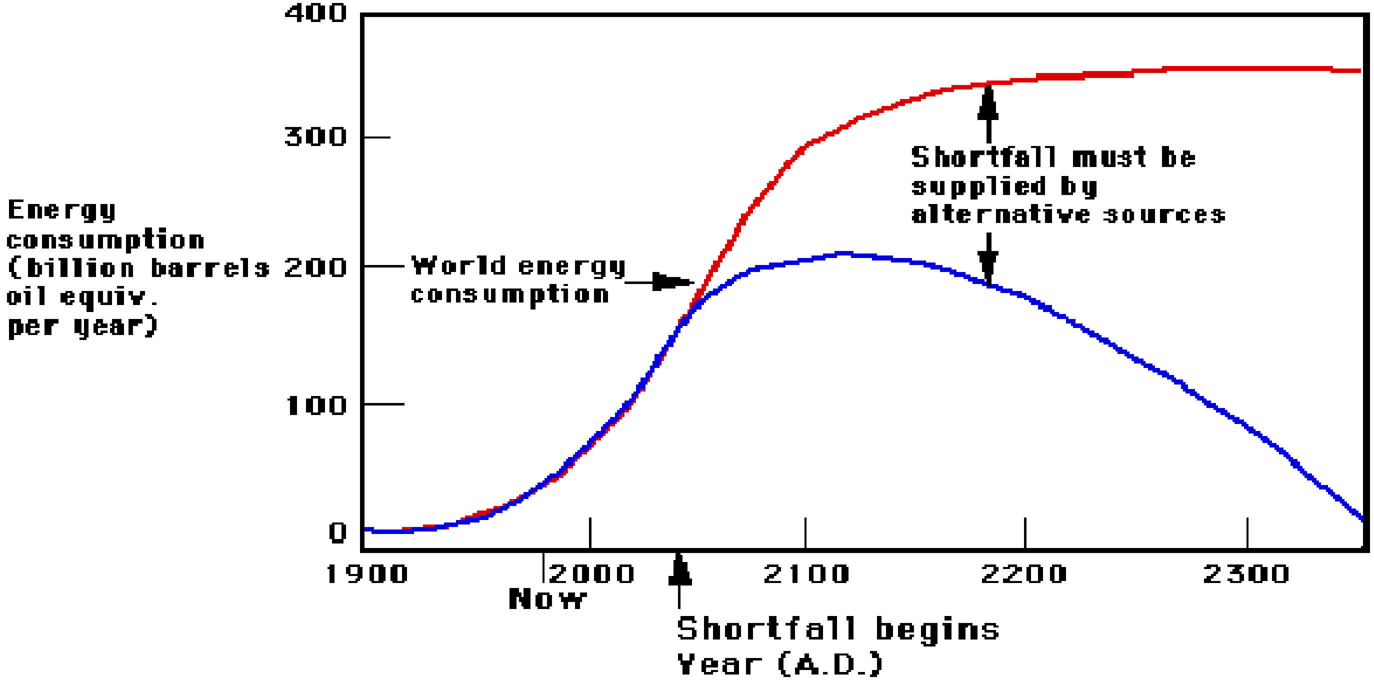
(www.plasmacoalition.org/about-plasma.html)

(www.plasmas.org/applications.htm)

Fusion Energy

Potential source of safe, abundant energy

New Sources of Energy Needed



Plasmas and Fusion Energy

Contemporary Physics Education Project

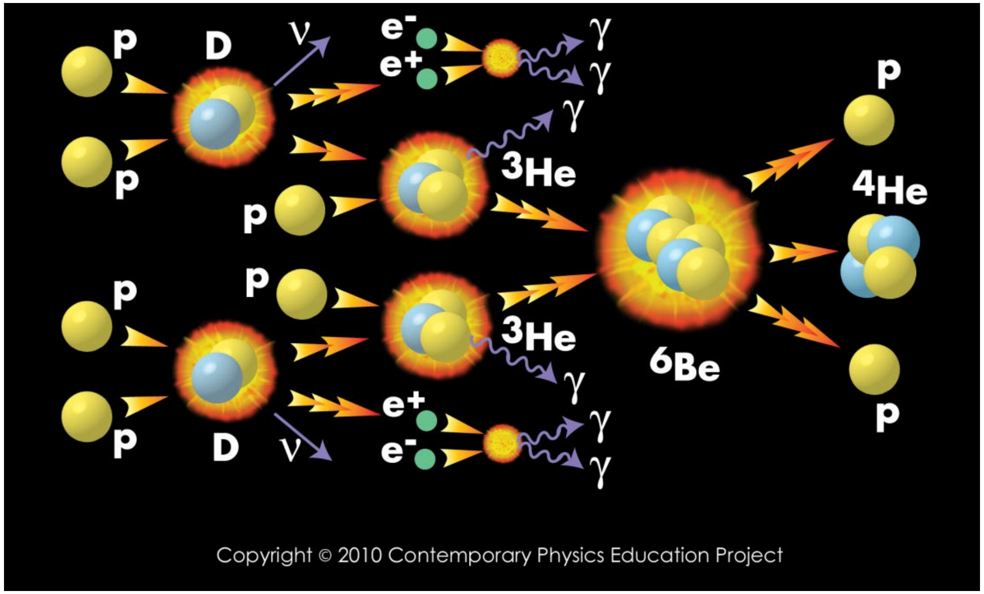
Much of plasma physics research has been motivated by the goal of controlled fusion energy.

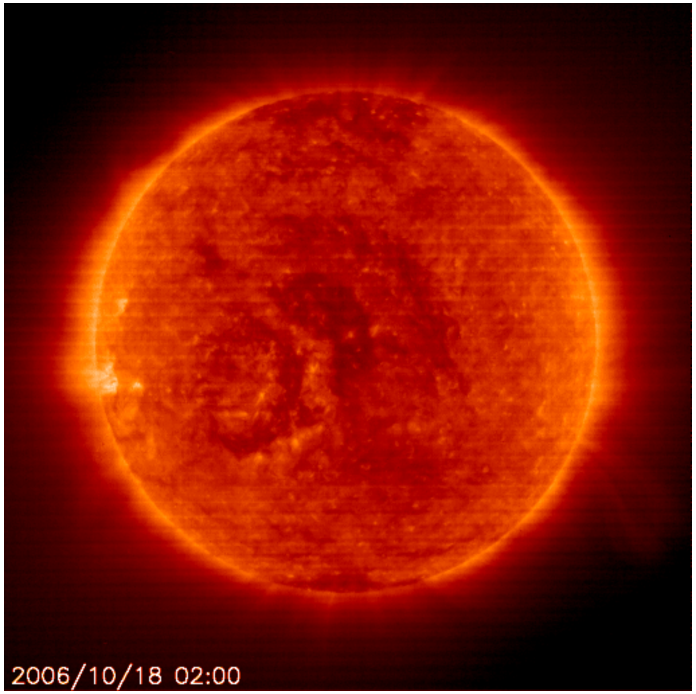
Fusion energy is energy which is released when two light nuclei combine to form a single more stable nuclei.

The sun and other stars derive their energy from fusion.

Fusion in the SUN

- Number of nuclei:
  90% H, 9% He, 1% others
- Solar core: 16,000,000° C
- 5 billion years more – slow process





http://sohowww.nascom.nasa.gov/data/realtime-images.html

Deuterium - Tritium (D+T) (Isotopes of Hydrogen)

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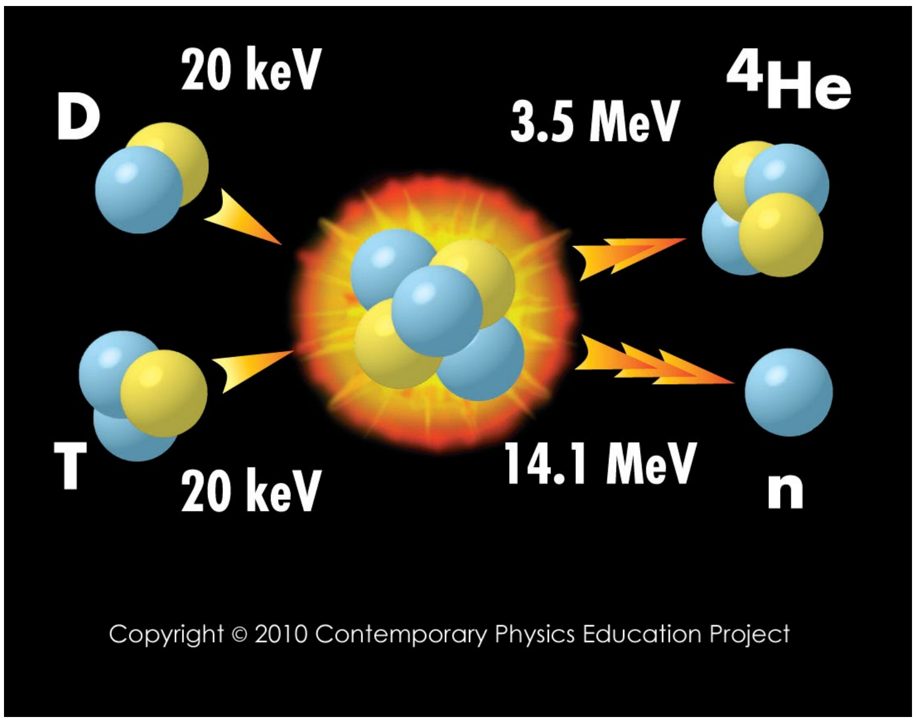
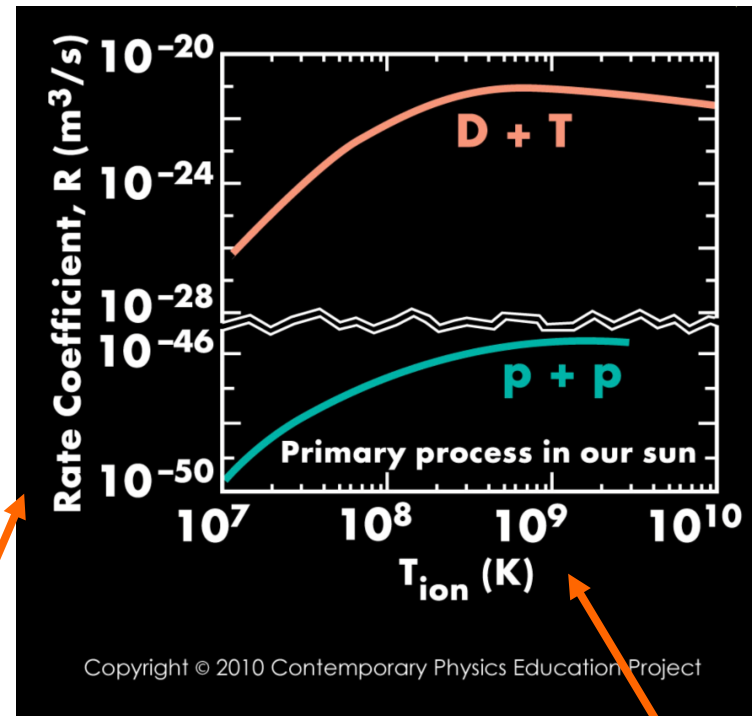
Reaction more plausible on earth



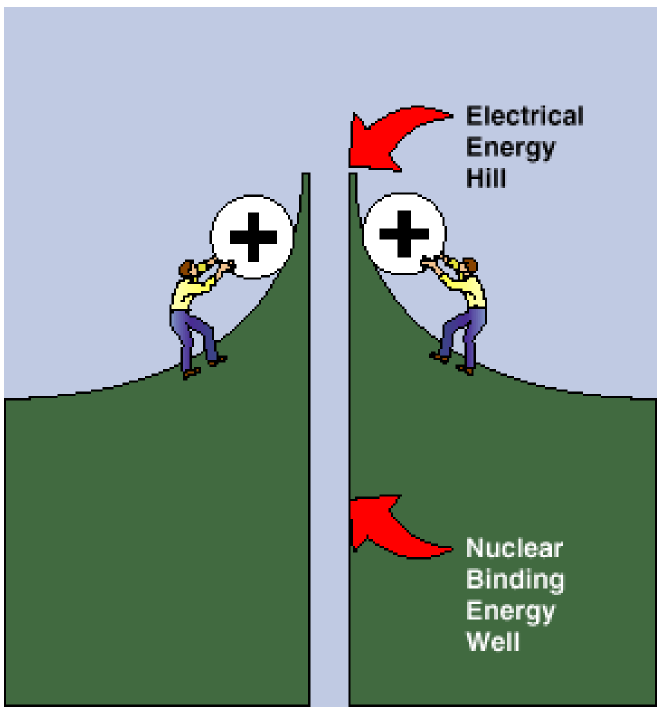


A number related to "probability" of reaction occurring at a given temperature.

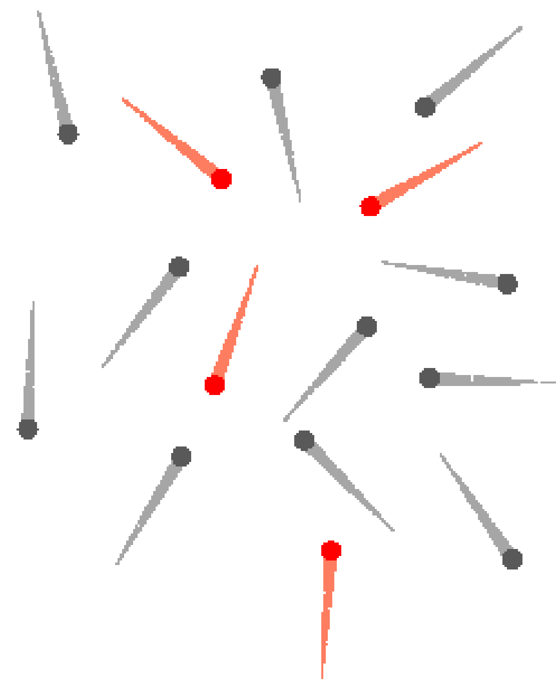
High T

High Temperatures and Densities Needed - A Plasma

High temperature



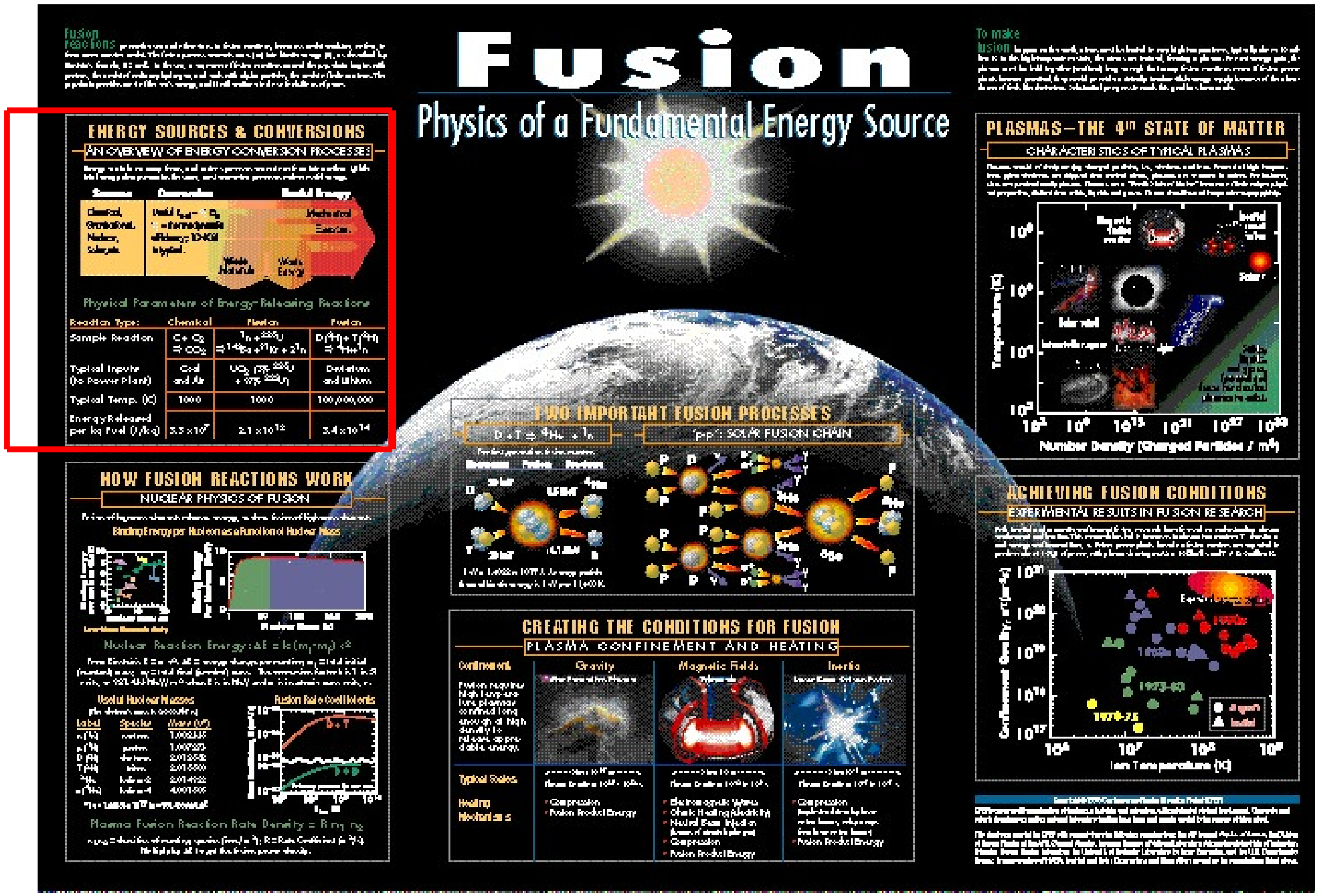
Will they meet?



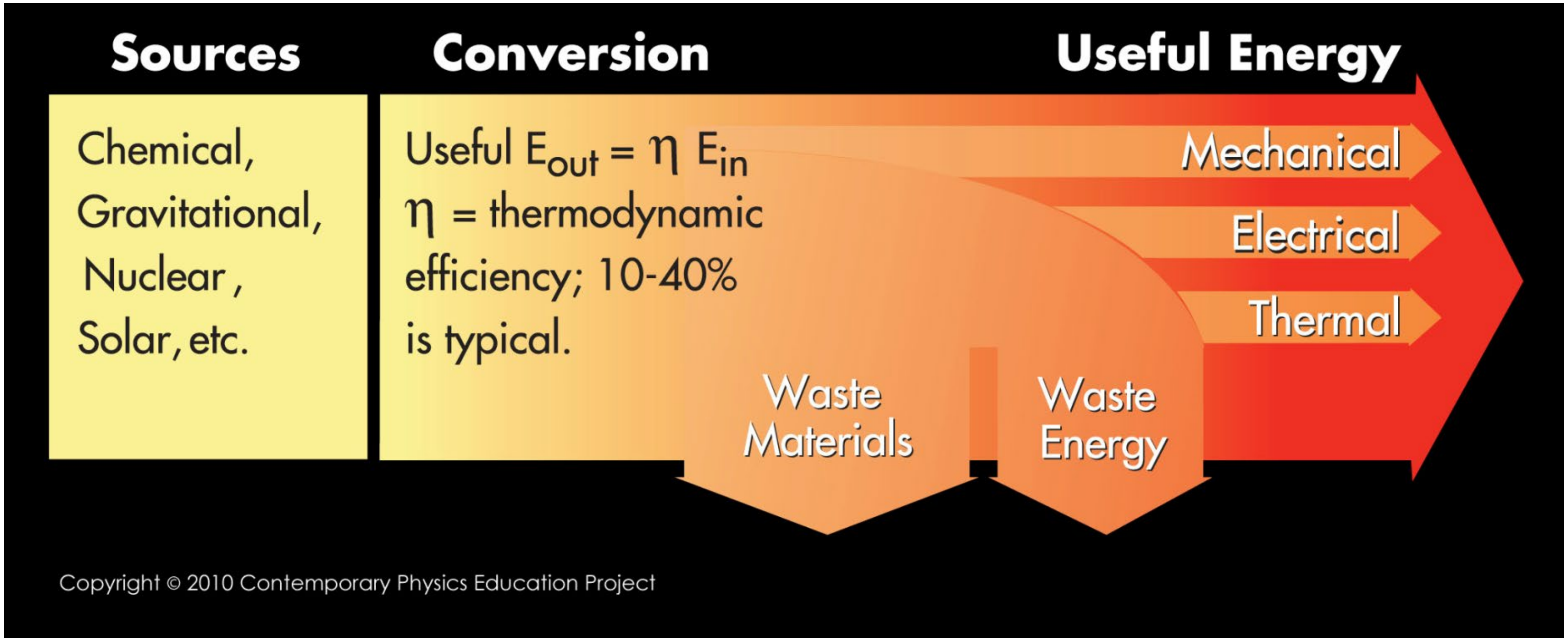
Long confinement time
Increased pressure

Energy Sources and Conversions

Contemporary Physics Education Project



Energy Sources and Conversions



Energy-Releasing Reactions

Contemporary Physics Education Project

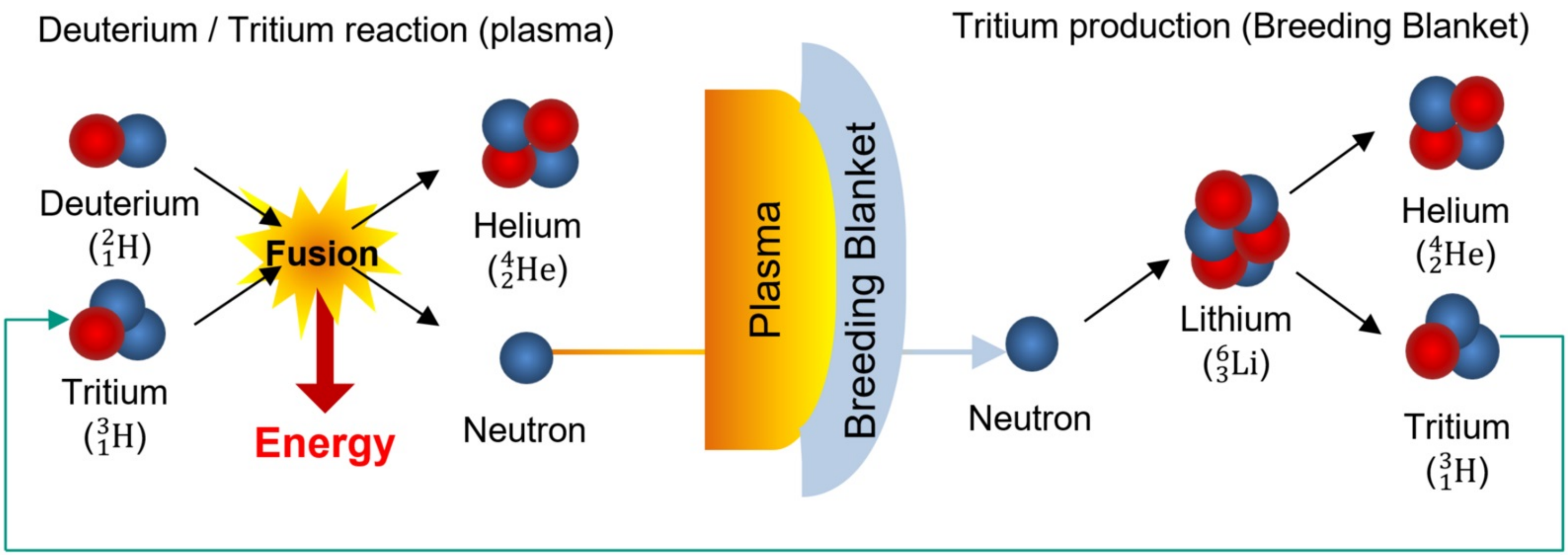
	Chemical	Fission	Fusion
Sample Reaction	C + O_2 -> CO_2	n + U-235 -> Ba-143 + Kr-91 + 2 n	H-2 + H-3 -> He-4 + n
Typical Inputs (to Power Plant)	Bituminous Coal	UO_2 (3% U-235 + 97% U-238)	Deuterium & Lithium
Typical Reaction Temperature (K)	700	1000	10^8
Energy Released per kg of Fuel (J/kg)	3.3×10^7	2.1×10^{12}	3.4×10^{14}

" …the lithium from a single laptop battery and the deuterium from 45 liters of water could generate enough electricity using fusion to supply an average U.K. consumer's energy needs for 30 years."
Daniel Clery, *A Piece of the Sun*

Why Lithium as a fuel?

Contemporary Physics Education Project

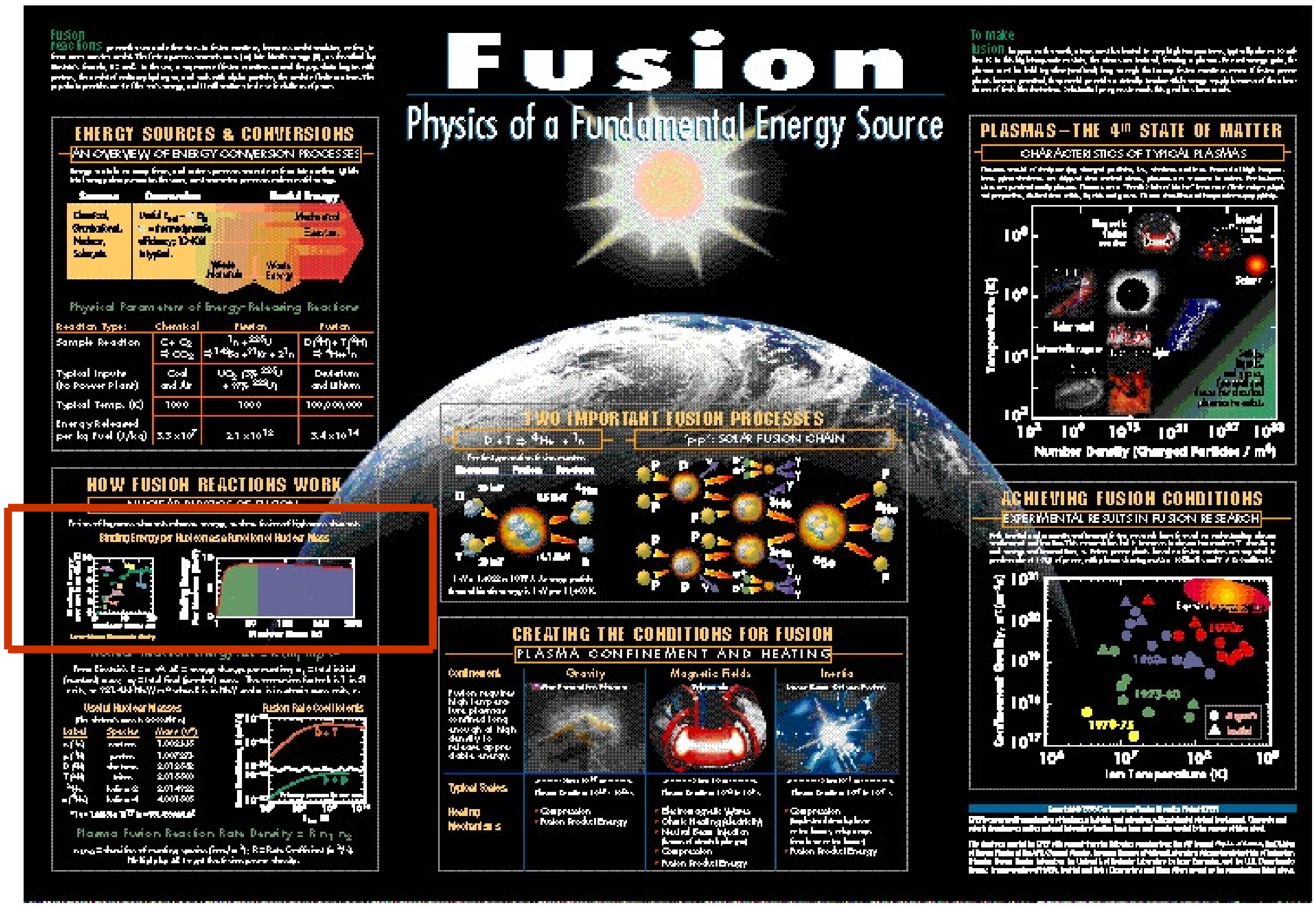
- Tritium radioactive with half-life of 12.3 years, so not readily available
- Use a reaction with Lithium to produce Tritium
- Lithium readily available



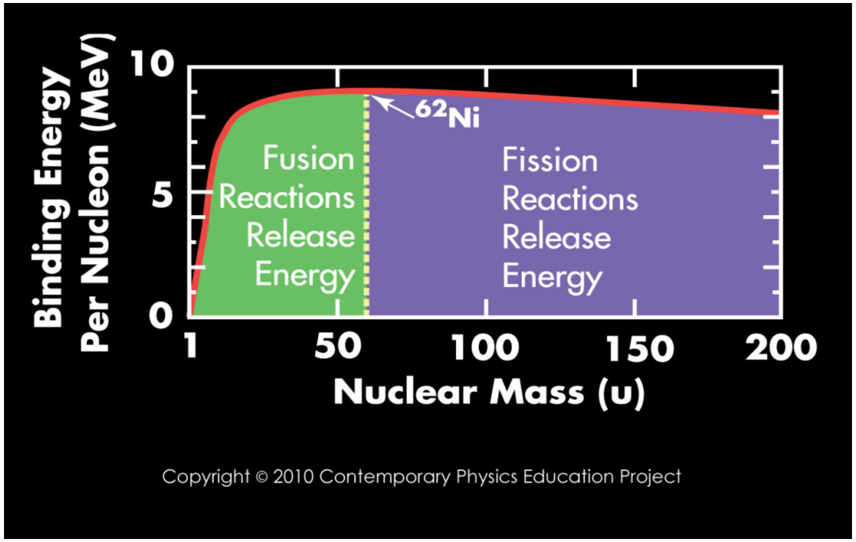
https://www.euro-fusion.org/news/2017-3/tritium-a-challenging-fuel-for-fusion/

Nuclear Binding Energy

Contemporary Physics Education Project



Fusion vs. Fission



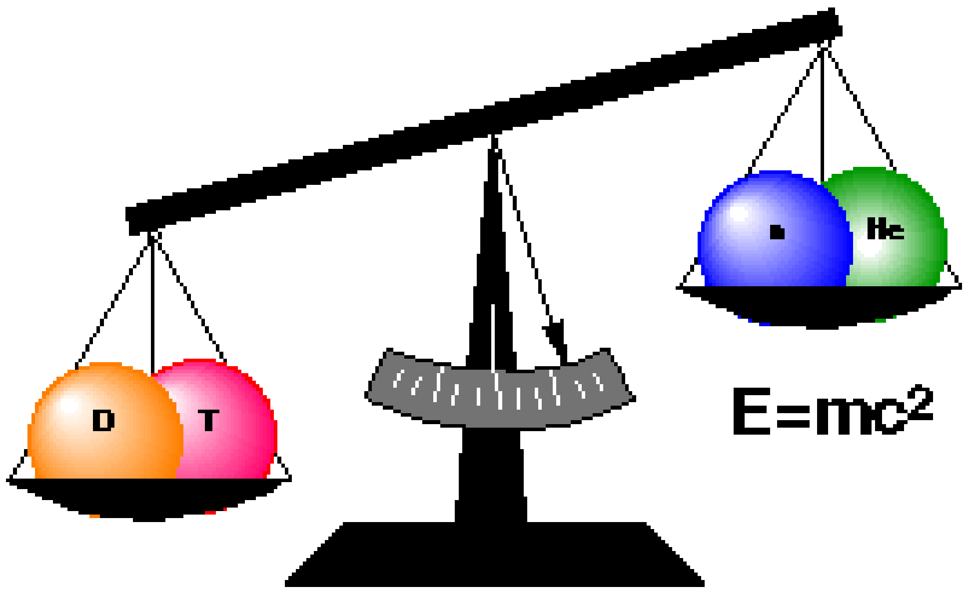
Energy released when go from smaller binding energy to larger binding energy

Combining low mass nuclei goes to higher binding energy - release energy - Fusion

Breaking a high mass nucleus into lower mass pieces goes to higher binding energy - release energy - Fission

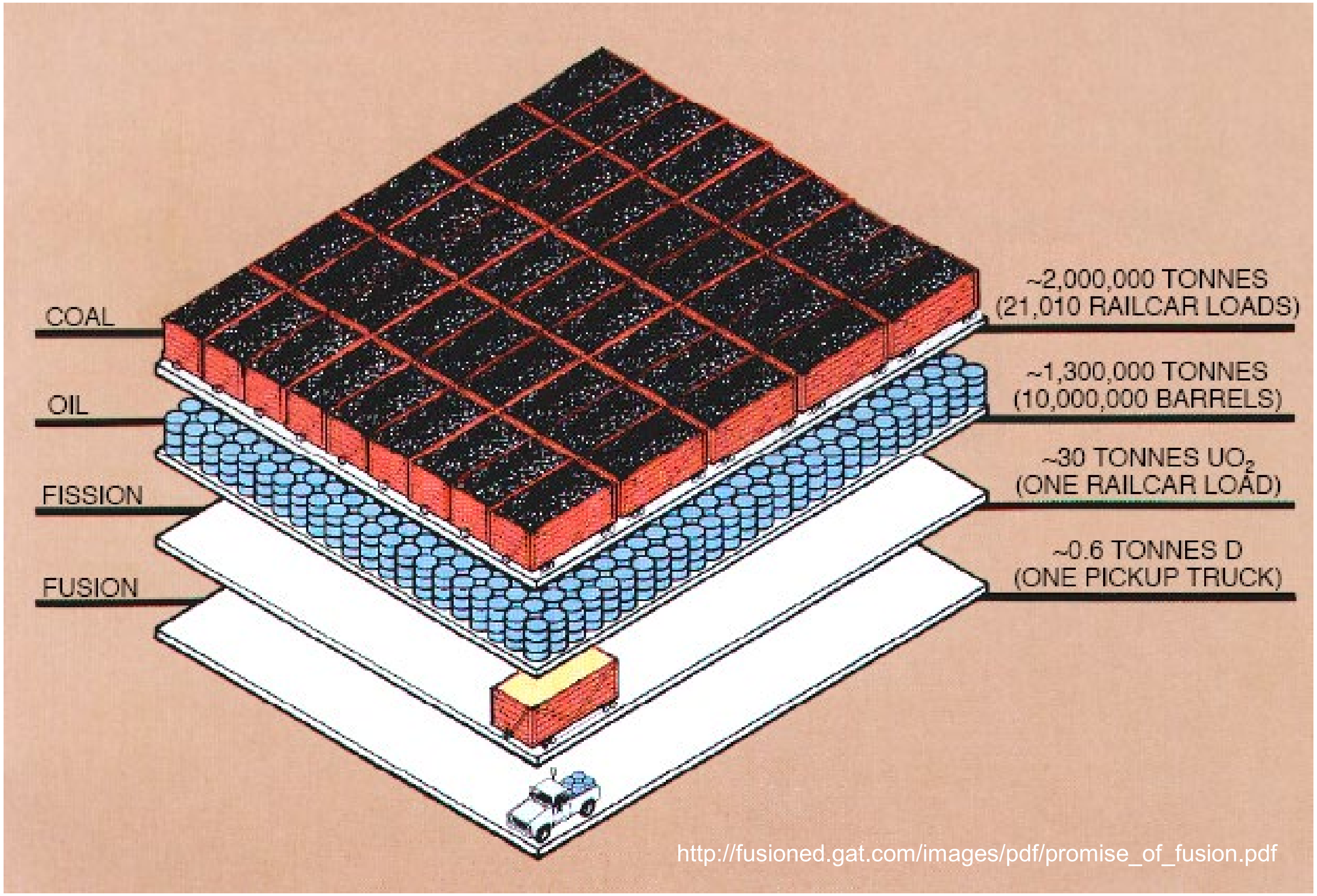
Mass Difference Converted into Fusion Energy

Contemporary Physics Education Project



- The fraction of mass “lost” is just 38 parts out of 10,000
- Nevertheless, the fusion energy released from just 1 gram of DT equals the energy from about 2400 gallons of oil

FUEL NEEDED FOR ONE YEAR OF POWER PLANT OPERATIONS (1000 MW)



Some Advantages of Fusion Energy

Contemporary Physics Education Project

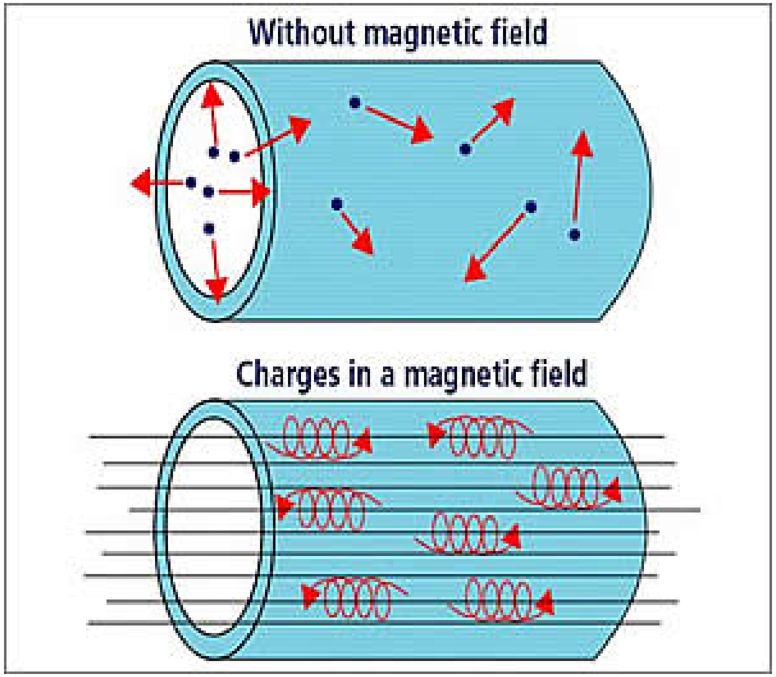
- Inexhaustible: “unlimited” fuel and available to all nations; Low land-use costs
- Clean: no greenhouse gases nor air pollution; Storage of short-lived radioactive components.
- Safe: no catastrophic accidents; Low-risk for nuclear materials proliferation.

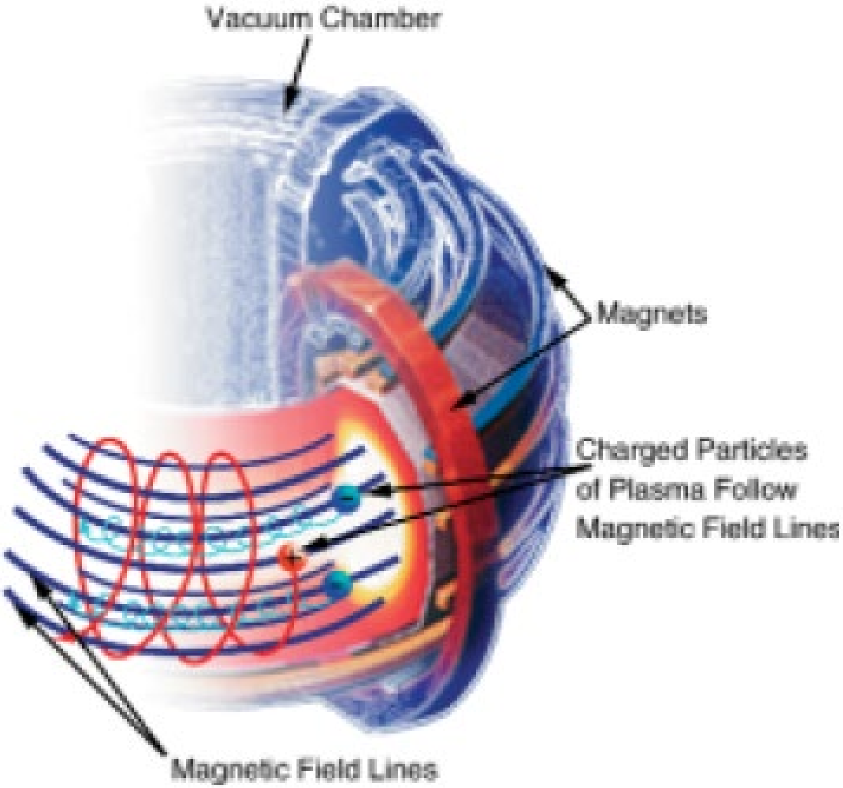
From: Kurzgesagt – in a Nutshell

Fusion Power Explained

https://www.youtube.com/watch?v=mZsaaturR6E

Magnetic Confinement

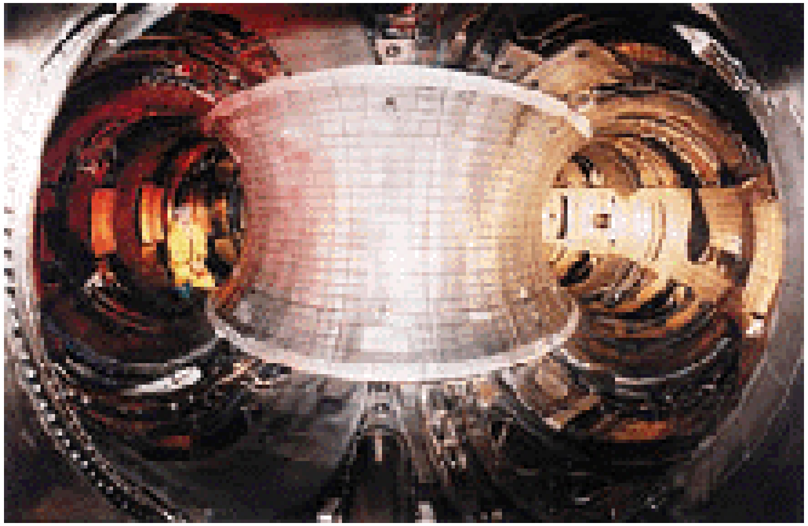




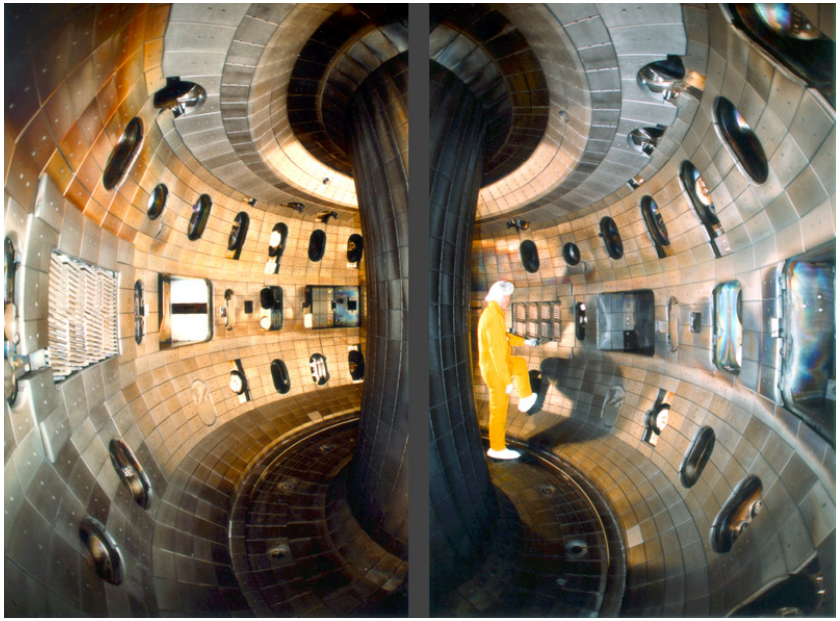
TOKAMAK

Magnetic Confinement

Contemporary Physics Education Project



Inside of the Princeton Plasma Physics Laboratory Tokamak TFTR. (1982 – 1997)



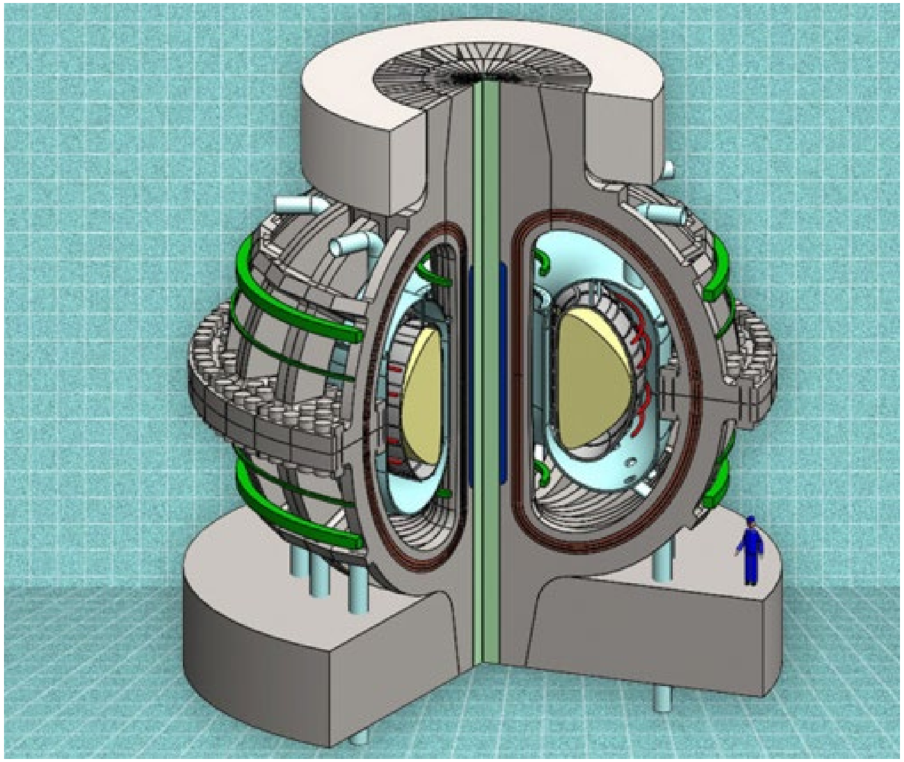
DIII-D General Atomics

MIT

Contemporary Physics Education Project

A small, modular, efficient fusion plant - ARC

ARC stands for "affordable, robust, compact." Though a tokomak by design, the MIT ARC Fusion reactor will use of a new class of commercially available superconductors tapes that generate significantly higher magnetic fields than standard superconductors. This will result in a possible power increase of almost 20 times. With this massive boost in power, MIT has been able to design a much smaller (and therefore cheaper) reactor that can still produce significant amounts of electricity.



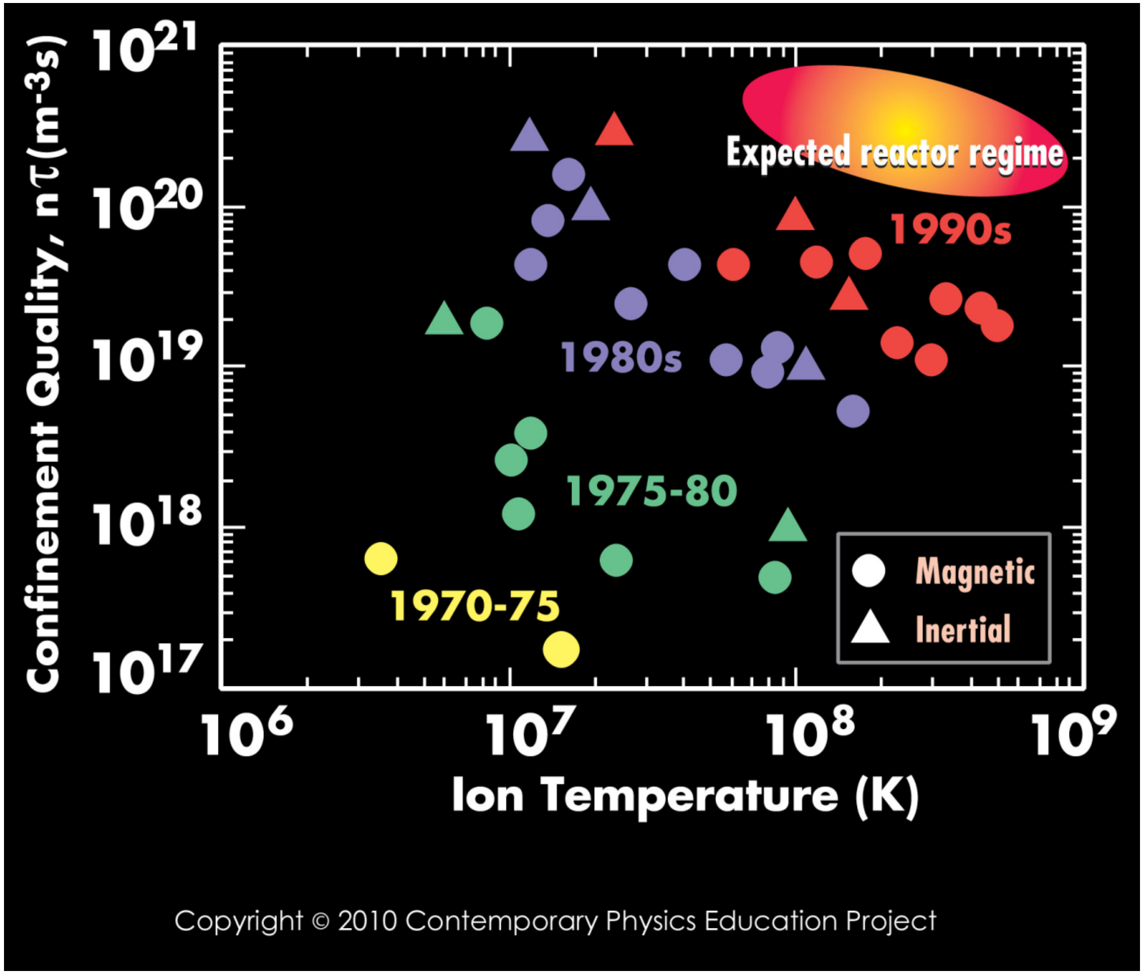
Inertia Confinement-National Ignition Facility

Three football fields could fit inside the NIF Laser and Target Area Building.

http://lasers.llnl.gov/

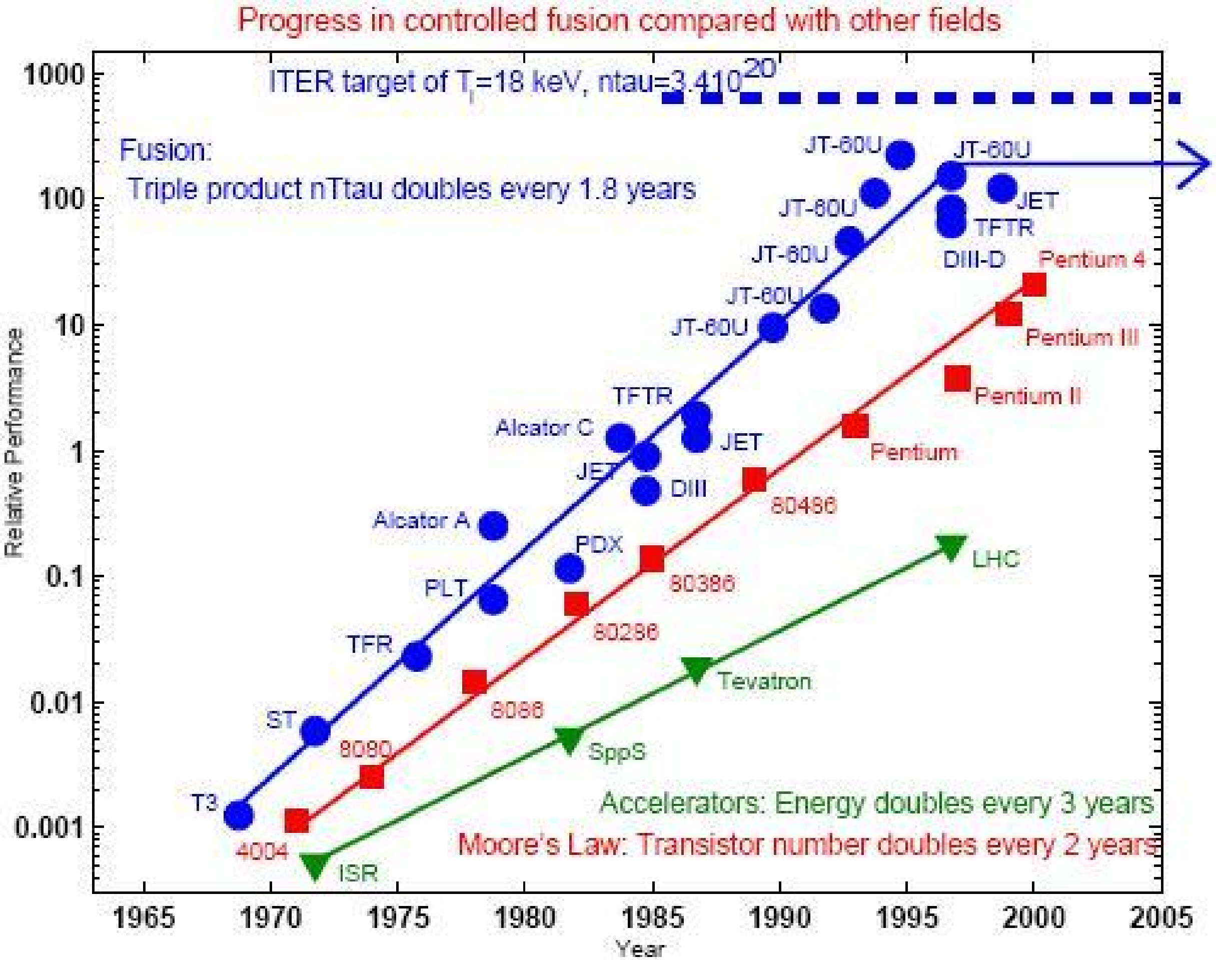
The world's largest and highest-energy laser, the National Ignition Facility (NIF), was dedicated May 29, 2009. NIF is conducting integrated ignition experiments that focus the energy of 192 giant laser beams on a BB-sized target filled with hydrogen fuel. One of NIF's goals is to fuse the hydrogen atoms' nuclei and produce more energy than the laser energy required to spark the reaction. This is the same fusion energy process that makes the stars shine and provides the life-giving energy of the Sun.

Achieving Fusion Conditions



Achieving Fusion Conditions

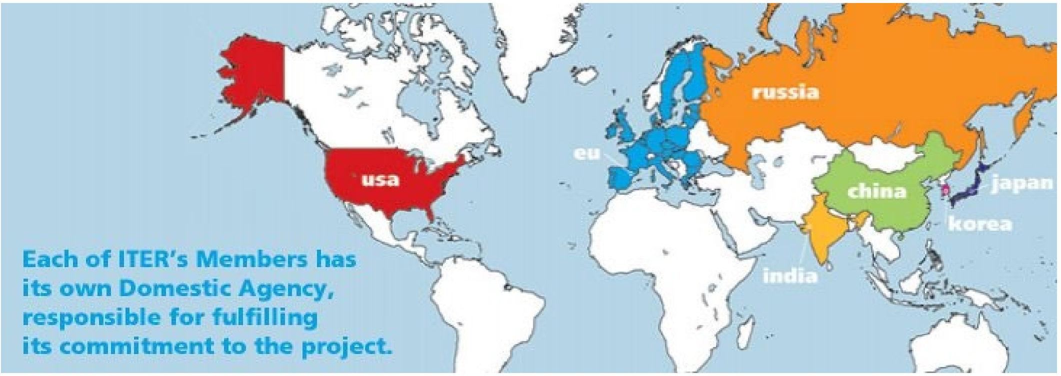
Contemporary Physics Education Project

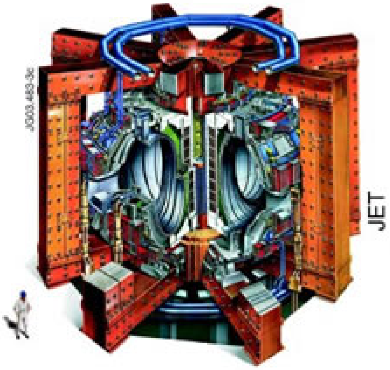


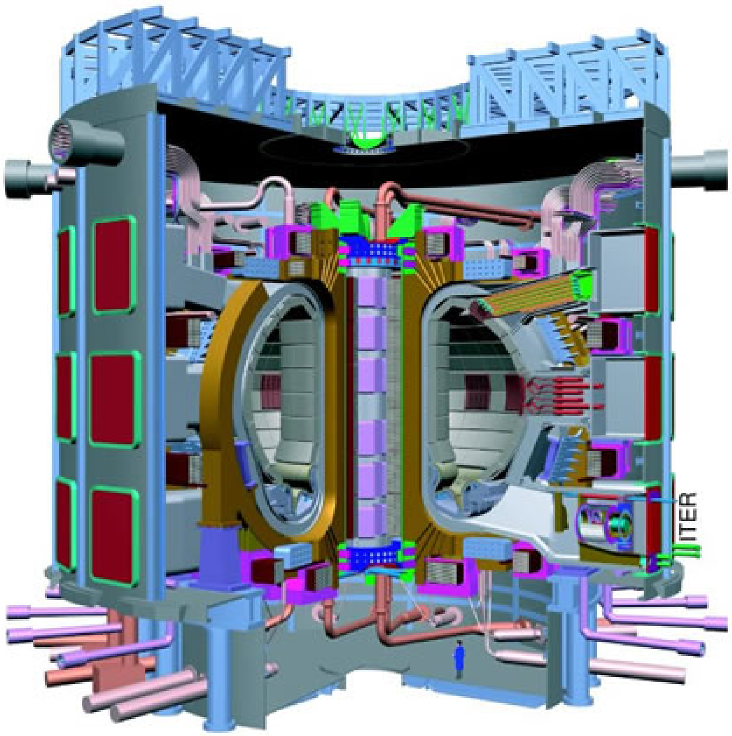
http://crppwww.epfl.ch/~weisen/publications/EPN_2005.pdf

The Next Step - ITER

Contemporary Physics Education Project

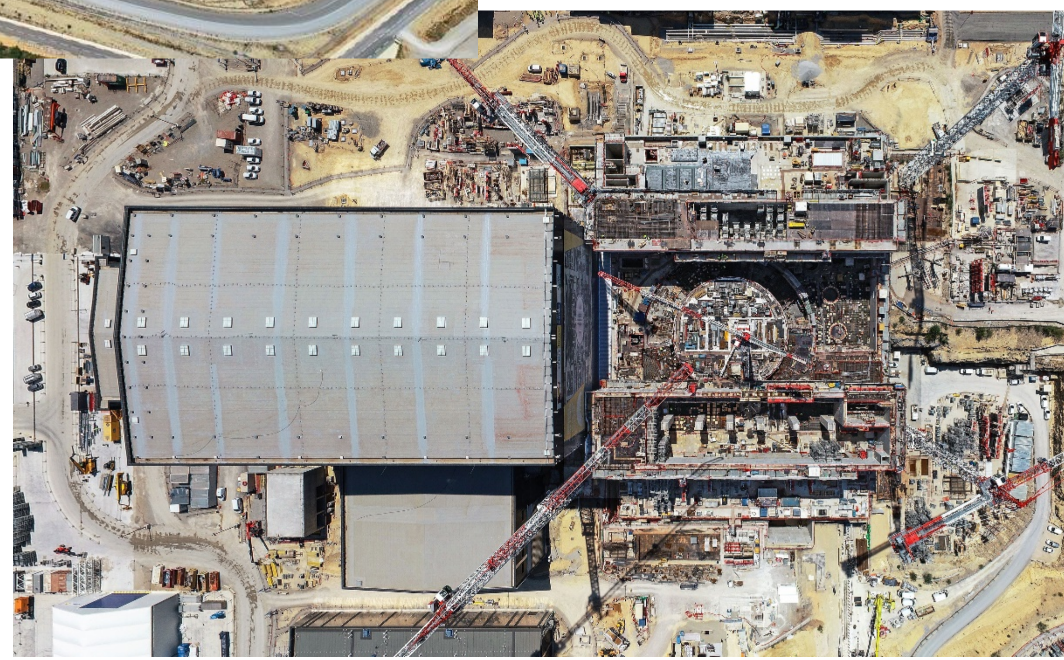






Cadarache, France

June 2019

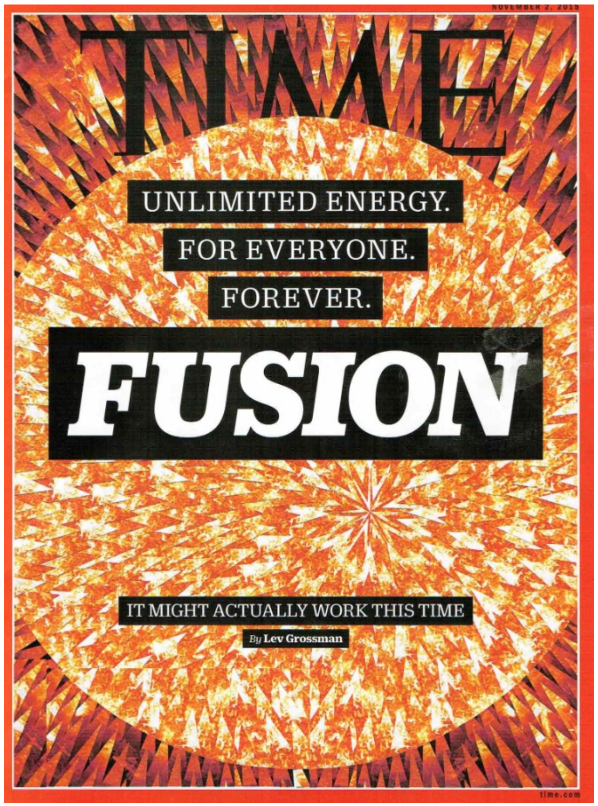


ITER Timeline

2005	Decision to site the project in France
2006	Signature of the ITER Agreement
2007	Formal creation of the ITER Organization
2007-2009	Land clearing and levelling
2010-2014	Ground support structure and seismic foundations for the Tokamak
2012	Nuclear licensing milestone: ITER becomes a Basic Nuclear Installation under French law
2014-2021	Construction of the Tokamak Building (access for assembly activities in 2019)
2010-2021	Construction of the ITER plant and auxiliary buildings for First Plasma
2008-2021	Manufacturing of principal First Plasma components
2015-2023	Largest components are transported along the ITER Itinerary
2020-2025	Assembly phase I
2024-2025	Integrated commissioning phase (commissioning by system starts several years earlier)
Dec 2025	**First Plasma**
2035	**Deuterium-Tritium Operation begins**

A Challenge for the 21st Century

Contemporary Physics Education Project



November 2, 2015

National Academy for Engineering

Their 14 *Great Challenges for the 21st Century* includes

Provide Energy from Fusion

Achieving Fusion Conditions

Where can I get information of the current progress in fusion/plasma science?

Check the **Other Fusion and Plasma Sites** list at

http://FusEdWeb.llnl.gov/

FusEdWeb | Fusion Education

https://fusedweb.llnl.gov

Home

Bringing The Power Source of the Stars Down to Earth

FusEdWeb Fusion Energy Education

Our Sun | Other Stars and Galaxies | Inertial Confinement | Magnetic Confinement

FusEdWeb: Discover Fusion

- CPEP's Online Fusion Course
- Other Fusion and Plasma Sites

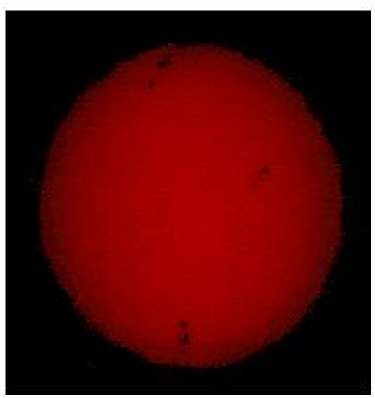
Great Sites

- Internet Plasma Physics EXperience
- GA's Fusion Energy Slide Show
- International Thermonuclear Experimental Reactor
- National Ignition Facility

Search

OFFICIAL HONOREE 2007 WEBBY AWARDS

Webby Awards Honoree
April 10, 2007



The Sun Runs on Fusion Energy

Like all stars, the sun is a huge fusion reactor, pumping out 100 million times as much energy in a single second as the entire population of Earth uses in a year!

Visit Layers of the Sun page to learn more.

Galaxies Run on Fusion Energy

This image shows hundreds of stars on the sides, with a barred spiral galaxy in the center. Each star is a huge fusion reactor, pumping out 100 million times as much energy in a single second as the entire population of Earth uses in a year! And each galaxy contains roughly 100 billion stars!

To learn more about stars and the fusion reactions which power them, try the IPPEX, CPEP,

https://fusedweb.llnl.gov/Intro/Inertial.html

Final

Contemporary Physics Education Project

From an interview with **Stephen Hawking**
Time, November 15, 2010

Which scientific discovery or advance would you like to see in your lifetime?

I would like nuclear fusion to become a practical power source. It would provide an inexhaustible supply of energy, without pollution or global warming.